Investigation of Possible Hydrogen Shielding Effect on Epithermal Neutron Activation Analysis

--A computation and experimental approach

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Introduction

Neutron activation is a popular analytical technique used to determine the presence and concentration of certain elements. It has several variations, including thermal neutron, epithermal neutron, fast neutron activation, etc, for different applications; all of those variations are non-destructive, and sensitive to small quantity. While trying to determine the concentration of Cl and Br in the light water solution, Dr. Landsberger’s team found the epithermal neutron activation analysis results were 25% lower than the conventional chemical method. They were not able to determine the cause of such discrepancy. This study was motivated to re-examine such discrepancy, and to study its possible causes. Furthermore, the study tries to determine if such discrepancy, if it exists, was linked with thermal neutron cut off or hydrogen absorption of neutrons.

A computer simulation using the Monte Carlo radiation transport software MCNPX was developed to radiate sample Cl & Br solutions of known mass concentrations in a simulated TRIGA reactor core at 500 KW steady state power. [1] The neutron activation rate of Br, Cl at each concentration was then calculated. Such procedure was then repeated for heavy water solutions. Finally, a cadmium shield was added to eliminate thermal neutrons; all samples were tested again using epithermal neutron activation. The actual neutron activation experiment was also carried out in the University of Texas’s TRIGA Mark II reactor. A total of 40 samples of Br & Cl solution (with and without Cd, in light water and in heavy water) were irradiated in the reactor at 500 KW steady state power.

Background and Theory

Neutron activation analysis utilizes a neutron source to bombard targeted elements with neutron flux; once such element absorbs a neutron, it is activated to an isotope of the same element—its proton number remains unchanged—which is usually radioactive. Those activation products then would decay with specific gamma emissions. By studying their emission spectra, one can identify the presence of elements by matching characteristic peaks, and estimate element concentration through counting the number of emissions. [2]

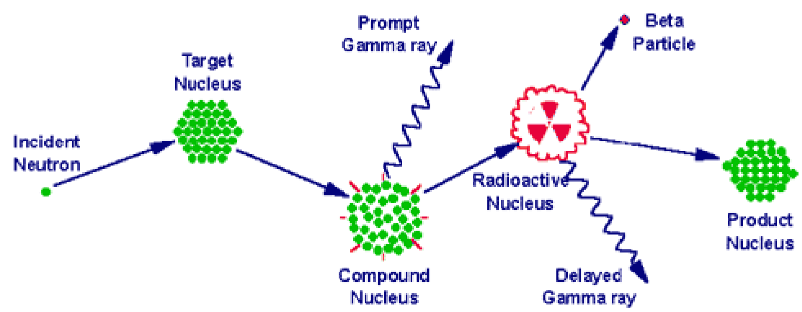

Figure 1, illustration of neutron activation reaction, the (n, γ) reaction
http://archaeometry.missouri.edu/naa_overview.html

The neutrons used for neutron activation analysis usually have low kinetic energies, and are classified as thermal neutron (~1ev) and epithermal neutron (1ev~1Mev) for the higher neutron cross-section at those energy levels. As one can observe from figures 2~3 below, in the thermal neutron region from 0 to about 1 ev, all Cl, Br, and Cd have a high thermal neutron cross-section; in the epithermal region from 1ev to 1Mev, their cross sections go down and exhibit much resonance before they finally enter the fast neutron region with low cross-sections.

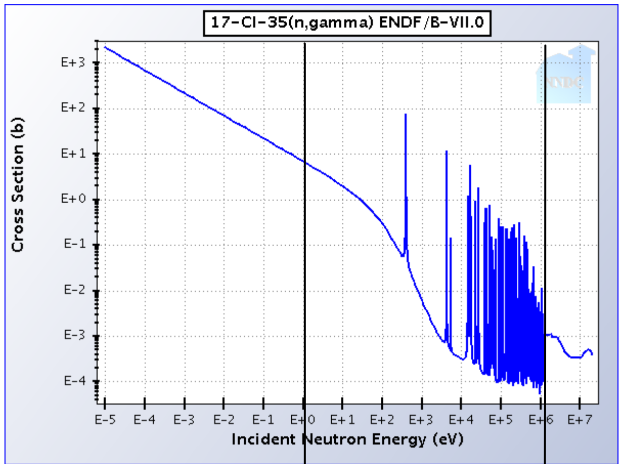

Figure 2, neutron activation cross-section spectrum for chlorine-35

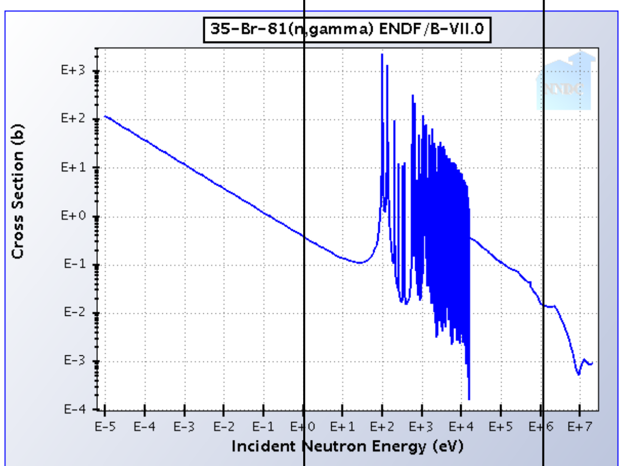

Figure 3, neutron activation cross-section spectrum for bromine-81

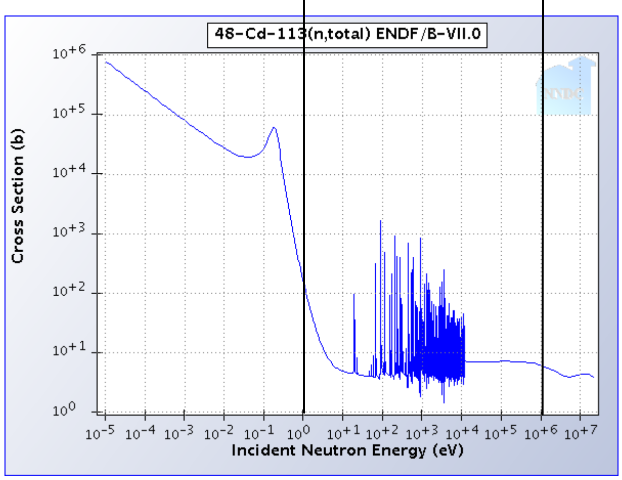

Figure 4, neutron activation cross-section spectrum for cadmium-113

Note the lines separate neutron cross sections in all three figures into thermal neutron and epithermal neutron regions. Also note the activation cross section of Br is about 1 order magnitude lower than that of Cl cross thermal and epithermal region.

This contrast between thermal neutron and epithermal neutron cross section is especially visible in cadmium, as seen in figure 4, with its thermal neutron cross section about 3 orders magnitude higher than those of Cl and Br; in epithermal neutron region, Cd's cross-section drops to about the same level as Cl and Br.

Because of the interfering interactions with other elements in the thermal neutron region, epithermal neutrons are sometimes preferred for select-irradiation to enhance the desired activation rate of targeting elements. [3], [4] In this case, cadmium shielding is usually used to eliminate thermal neutron from the volume containing the testing specimen due to cadmium's very high thermal neutron cross sections

Various causes for inaccuracy in (thermal and epithermal) neutron activation analysis have been reported, such as spectrum peak area distortion, interfering isotopes, the irregular shape of epithermal neutron distribution in the reactor, and hydrogen shielding. [4], [5], [6], [7] However, spectrum peak area distortion and irregular epithermal neutron distribution from the reactor are unlikely in the well-calibrated neutron activation facility at UT TRIGA reactor, as corrections for these had been applied. Interfering isotopic activation due to higher energy neutron should also be minimal in the epithermal neutron activation experiment. [6], [7], [8], [9]

Given the abundance of hydrogen in the sample and its large neutron cross section, hydrogen shielding appeared to be possible. As shown in figure 5 and 6, the total cross sections for hydrogen in thermal and epithermal neutron region is comparable if not higher than the cross sections for Cl and Br. The neutron cross section of deuterium, on the other hand, is roughly one order of magnitude lower across the same energy spectrum.

This study compares simulated activation rates of Cl and Br in both light water and heavy water solutions at 5 different concentrations (0.001%, 0.01%, 0.1%, 1%, 10%). Experiments were also conducted to verify the computational results. These results would determine if hydrogen shielding indeed was responsible for the aberrant experimental result in the epithermal neutron activation analysis.

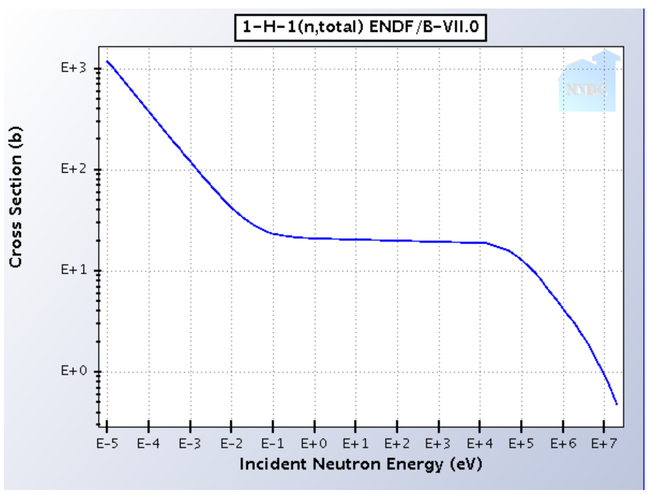

Figure 5, total neutron cross section spectrum for hydrogen.

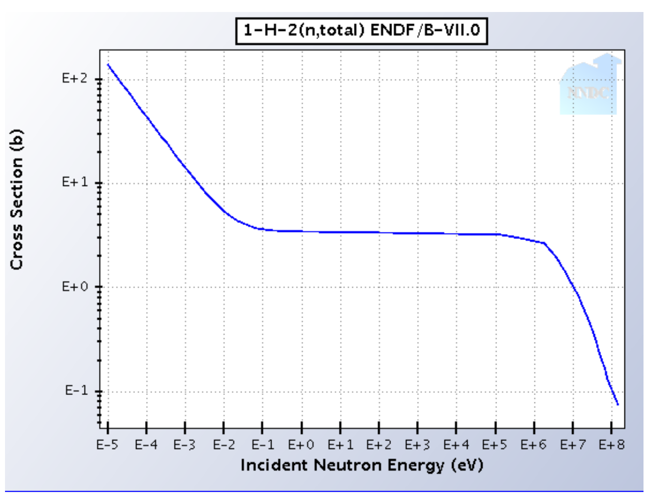

Figure 6, total neutron cross section spectrum for Deuterium.

Computer Simulation Methodology

To simulate the radiation field in the UT TRIGA reactor, the Monte Carlo radiation transport software MCNPX code was used. [1] An existing deck developed by Braisted provided the base model of the geometry and material compositions for the UT TRIGA reactor. [10] Figures 7 and 8 below show the geometric structure of the deck as plotted in the MCNP visual editor. The modeled reactor core is a 1.5 m tall, 1.4 m diameter cylinder submerged in water (pink areas in the figure). The U-Zr-H fuel pins (light blue tall cylinders) are arranged in a hexagonal cell lattice in the center of the reactor core, with four control rods (three orange and one purple cylinder) situated in the middle. The testing sample will be loaded in the reactor for neutron activation at spots indicated by the arrows in figures 7 and 8.

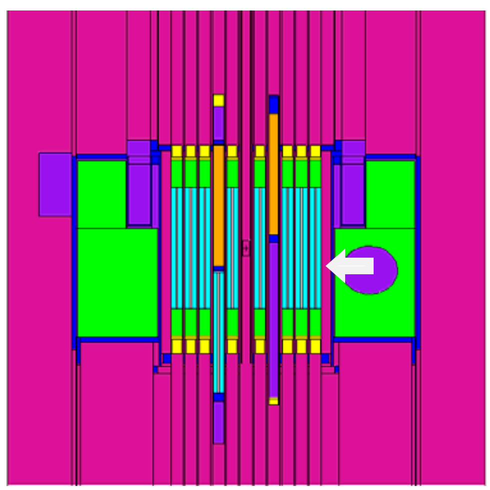

Figure 7, Side view of the UT TRIGA reactor from the existing MCNPX deck. Note, the arrow is pointed at the sample location in the reactor.

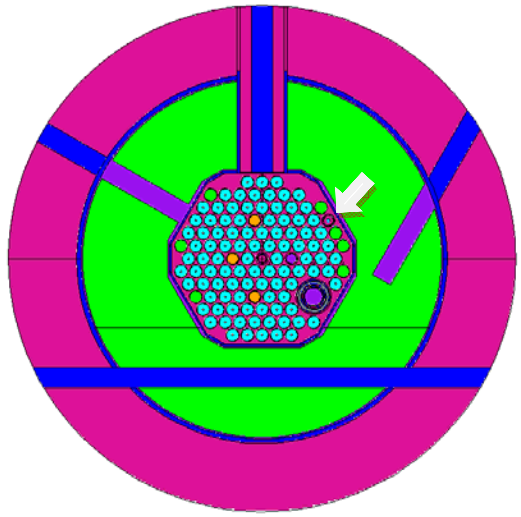

Figure 8, Top view of the UT TRIGA reactor from the existing MCNPX deck. Note, the arrow is pointed at the sample location in the reactor.

The radiation level of the TRIGA reactor was estimated using the criticality calculation feature of MCNPX. This so-called K-code calculation obtains the multiplication factor Keff by tracking 10000 neutrons per generation for 60 generations. The initial guess for Keff is set to 1.0; the results of the neutrons and the Keff of the first 30 generations are discarded as the fission source must converge to its fundamental eigenmode. For better statistical results of the sample region in the much larger reactor core, more tracking particles and generations would be preferred. However, excessive computational resources would be required that way. The simulation of 10,000 particles and 60 generations took 20 minutes per run on an Intel Pentium 4 HT 3.00GHz computer.

Upon first execution, the K-code calculation revealed a slightly supercritical system with Keff=1.02~1.03. The TRIGA model was then modified to lower the four control rods each by about 10 cm to reach criticality. Subsequent K-code calculation showed a critical system with Keff = 1.000 +/- 0.001.

Because the MCNPX simulation generates the neutron flux distribution of a steady state reactor at random power level, the actual neutron flux of TRIGA reactor at 500 KW steady state has to be calculated using a power scale factor. To determine the power scale factor, the power output of the simulated critical system was estimated with two MCNPX building tallies F4 and F7. Using F4 tally option 2, which tracked fission neutron flux, the average fission rate density of a single fuel pin was found to be 1.045E-3 fissions per cubic centimeter per second. The volume of each fuel pin was found to be 384.96 cm^3 and the reactor core holds 98 fuel pins.

$$Average\ fission\ rate = 1.045\,e-3\ {}^{fissions}/_{sec.*\,cm^3} * 384.96\ cm^3\ * 98\ fuel\ pins$$
$$= 39.42\ {}^{fissions}/_{sec}$$

$$Average\ fission\ energy\ output$$
$$= 39.42\ fissions/sec * 200\ MeV\ /\ fission\ *\ 1.602e-13\ J\ /\ MeV$$
$$= 1.3\ e-9\ W$$

This number was double-checked by using F7 tally, which tracked average fission energy deposition of each fuel cell. Since samples would be irradiated at a steady state power of 500 Kilowatts, a multiplier was calculated.

$$Energy\ Scale\ factor = {}^{500{,}000\ W}/_{1.3\ e-9\ W} = 4.345\ e\ 14$$

This multiplier would be used to adjust the results of all subsequent MCNPX tallies so that they corresponded to the radiation field intensity at 500 kW of fission power.

The samples, which consisted of chlorine and bromine solution of differing concentration in a polyethylene vial in each trial, were then developed using MCNPX. The cylindrical vial is 1.6 cm tall, 0.5 cm ID, 0.55 cm OD. Inside, NaCl and NaBr solution of 0.001%, 0.01%, 0.1%, 1%, and 10% in both water and heavy water (D_2O) were prepared. They were loaded in the sample holder as marked in figures 7, 8 and 9.

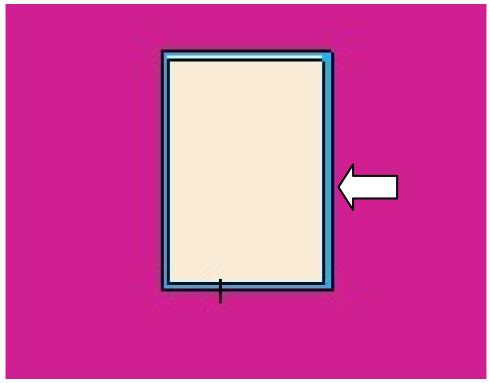

Figure 9, the polyethylene vial (the thin blue layer indicated by the arrow) is emerged in water. It held desired testing material chlorine and bromine solutions of different concentrations inside.

The neutron activation rate of each specimen was obtained using an F4 tally and scaled up with power scale factor and element number density. See table A in Appendix for the calculation and the complete list of number density values for various elements in different specimen. The resulting activation rate density of samples was in units of #/cm^3/sec. Furthermore, the activation rate was assessed within two different energy bands: < ~1 ev for thermal neutrons, and 1ev-1Mev for epithermal/fast neutrons with the energy tally F.

The preliminary results had uncertainties of 40% when 10,000 neutron particles per generation were tracked. It appeared to be that 10,000 neutron particles could not provide a sufficient number of neutrons for a relatively small sample region in the reactor. In order to decrease the uncertainty to an acceptable level (<10% in most cases), the number of particles tracked was increased to 1,000,000, which would be expected to decrease the uncertainty from 40% to 4%. However, the computational time for a single run of the MCNPX code then became close to 3 days. Therefore, a surface source substitution method by Wilson and Schneider was used to reduce computational requirements, as seen in figure 4. [11]

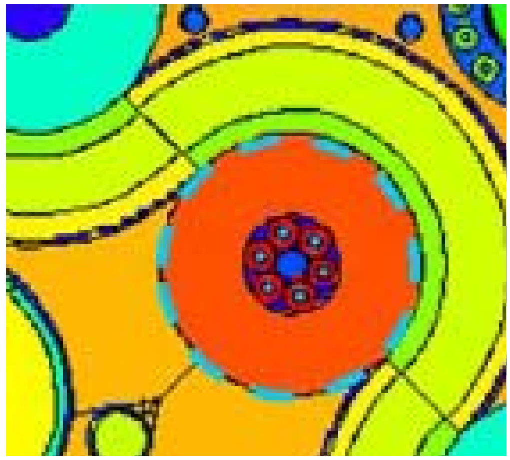

Figure 10, the surface source substitution method developed by Wilson and Schneider. Note the dash-lined circle as the surface source.

A three plane surface (one cylindrical surface, one top, and one bottom planes) surrounding the vial of specimen in the sample location is developed. As one can see in figures 11 and 12, the surface source that encloses the testing specimen was much smaller than the whole TRIGA reactor. An MCNPX SSW command was used to record the neutron flux through those surfaces that eventually entered the sample. After an initial run, a surface source file recording all neutron influx was generated and was then renamed as rssa for subsequent use. A new MCNPX source file was also developed to take advantage of the rssa surface source. Geometrically, the deck now only included the surface source, and the vials and samples inside, as seen in figure 13. An SSR command was used to recall the rssa file for the surface source configuration. F4 tallies with various multipliers were once again used to estimate the activation rates. Now only the initial run used the original code with full TRIGA reactor deck, which took about 3 days; all the subsequent simulation took much less computation time (less than 20 sec. each).

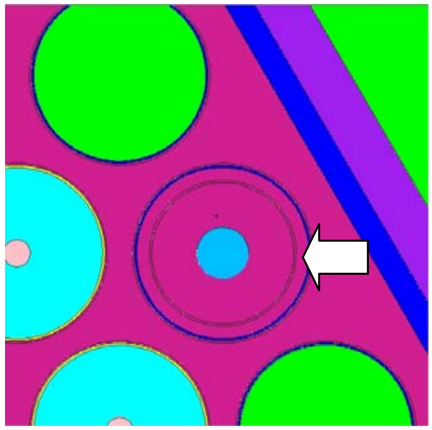

Figure 11, the close up of the sample holder location; note the thin layer indicated by the arrow is the surface source in the original deck.

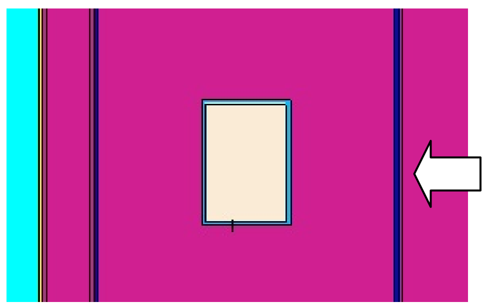

Figure 12, the side view of the sample holder location, note the thin layer indicated by the arrow is the surface source in the original deck.

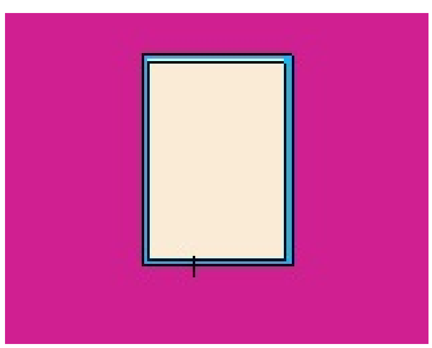

Figure 13, the new MCNPX code with only the surface source, the vial and samples. Note, the empty space outside the purple water is the outer boundary of this deck.

Using the new surface source, the activation rate of Cl, Br, H, D from NaCl and NaBr solution of 0.001%, 0.01%, 0.1%, 1%, and 10% in both water and heavy water (D_2O) were calculated. Finally, the rate was calculated again for all specimens with a Cd foil of 1mm thickness wrapped tightly around the polyethylene vial. Once again, the activation rate was broken into two energy levels of <1 ev for thermal neutron, and 1 eV~1 Mev for epithermal neutrons.

Neutron Activation Procedures and Calculation

The light water and heavy water solution of NaCl, NaBr were prepared using 100ml flasks, NaCl, NaBr salt, deionized light water and heavy water. **10.7 gram** of NaCl (10% of NaCl light water solution has a density of 1.07g/ml) was weighed and dissolved in deionized light water in a 100 ml flask. Light water was added until the solution reached 100 ml mark. 10 ml of the newly made10% NaCl light water solution was transferred to a new 100 ml flask and refilled with light water until the solution reached 100 ml mark. The 1% NaCl light water solution was then made. In a similar fashion, the 0.1%, 0.01% and 0.001% NaCl light water solutions were made. NaBr light water solutions at different concentrations were also made in the same fashion. Note the density of 10% NaBr light water solution was also about 1.07 g/ml. **11.7 grams** of NaCl (density of 10% NaCl heavy water solution is 1.17g/ml) was weighed and dissolved in deionized heavy water in a 100 ml flask. Adding heavy water was continued until the solution reached 100 ml mark to make 10% NaCl heavy water solution. The above process was repeated until all 1%, 0.1%, 0.01% and 0.001% mass concentration solutions were made. The process was repeated again to make NaBr heavy water solution at the above mentioned five concentrations.

Due to the available reactor time, only 20 NaCl samples in light water and heavy water were tested in thermal and epithermal neutron activation tests.

After the sample solutions were prepared at the required mass concentration, they were then transferred into polyethylene vials. The vials were filled halfway, and then placed near the core of the reactor using the pneumatic system. The samples were irradiated at 500 KW steady state for 10sec~10 minutes depending on the mass concentration. The pneumatic system then pulled them out of the core; the samples were weighed and transferred into a new polyethylene vial to avoid the background interference of activated elements in the vial itself. The gamma emissions due to the decay of Cl-35 were counted using High Purity Germanium gamma ray detectors. The gamma spectrum was then produced as seen in figure 14. The peaks of gamma emission for Cl-35 was observed at 1642 kev; the area under the peak, as seen in the lower window of figure 14, was given enough count time to reach 5000 count to reduce uncertainties. The dead time was kept under 5% during the counting process.

Based on the measurement of the activity, count time, decay time, setup, geometry, and detection efficiency, software then applied several corrections for each sample, and calculated the mass concentration of targeted elements in the sample. Note, two standard reference material of tomato leaves (SRM 1573a, 6600 pmm Cl) were irradiated with and without cadmium coating each for 1 min at 500 KW steady state.

The activation rate of the element and its concentration are related as:

$$N_{(A+1)} = \frac{\Phi \sigma_{aA} N_{oA}}{\lambda_{(A+1)}} \left[1 - e^{-\lambda_{(A+1)} t_R} \right] e^{-\lambda_{(A+1)} t}$$

where $N_{(A+1)}$ is the atomic number density of activated isotope (activation rate if we normalized by 1 sec. of irradiation time); σ_{aA} is the neutron absorption cross section of the original isotope, N_{oA} is the number density of the original isotope, t_R is the irradiation time (1 sec. in our simulation), t is the time after irradiation, and $\lambda_{(A+1)}$ is the decay constant of the activated isotope. [12] [13] [14] Assuming irradiation time is 1 sec, time after irradiation is short and the half-life is relatively long. The concentration of the element in the sample can be calculated as:

$$N_{aA} = \frac{N_{(A+1)}\lambda_{(A-1)}}{\sigma_{aA}\phi}$$

Oftentimes, the mass concentration of the elements was established using the relative method. The sample and a standard reference of known material concentration were irradiated together in the reactor. By comparing the gamma emission of the activated product, the concentration of the sample can be easily determined. [13] The simple calculation can be carried out as:

$$C_{sample} = C_{std\,ref.}\frac{W_{std}}{W_{sample}}\frac{A_{sample}}{A_{std}}$$

where C is the element concentration, W is element weight and A is element activity. In addition, the use of standard reference material provides correction coefficients for the reactor configuration, geometry, and detector efficiency for the calculation. [14] [15]

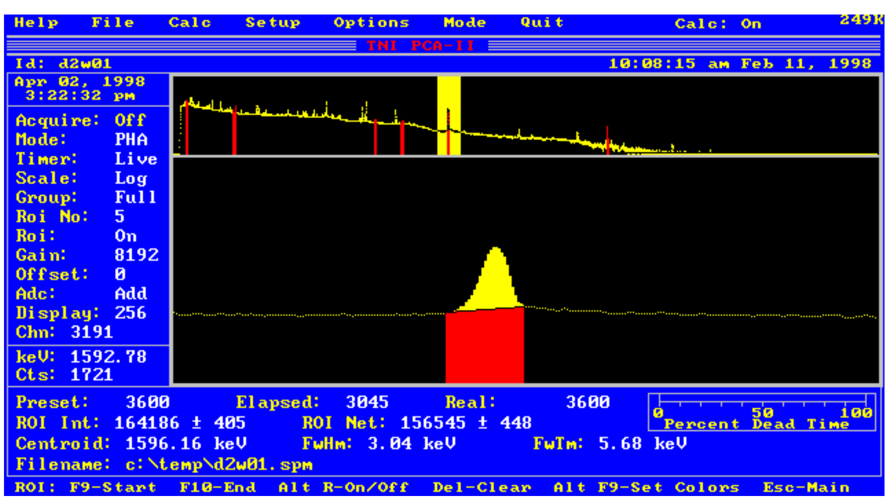

Figure 14, gamma spectrum of neutron activation analysis

http://reactor.engr.wisc.edu/naa/moreNAA.htm

Data Analysis

Computer Simulation

The total activation (capture) rate density of Cl, Br, H, D and their uncertainties from the simulation are obtained from the F4 tally output file and scaled as described above. The activation rate per atom (probability of activation per atom) is calculated by dividing the total activation rate density by number density of respective elements. See Table B in Appendix for complete list of values. Note, all the activation rates are normalized by 1 sec. irradiation time.

For the neutron activation rate of Cl without cadmium shield, figure 15 showed that the epithermal neutron and total activation rate of Cl were identical in light water and heavy water. In both light water and heavy water samples, the epithermal neutron activation rate was about two orders of magnitude lower than the thermal (and total) neutron activation rate. The epithermal neutron and total activation rate of hydrogen in light water is about three orders of magnitude higher than deuterium in heavy water.

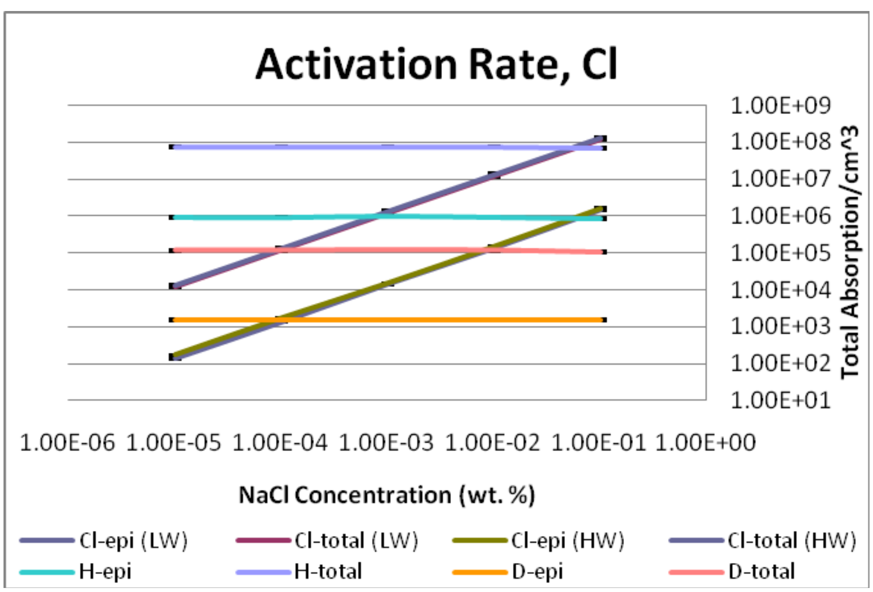

Figure 15, neutron activation rate of Cl in light water and heavy water

For neutron activation rate of Br without cadmium shield in figure 16, similar results were observed. From there, it was concluded that the Cl and Br activation rates were linear (in the lognormal graph) in their concentration in the solution, implying that even at high concentrations the salts did not induce a significant perturbation to the local radiation field.

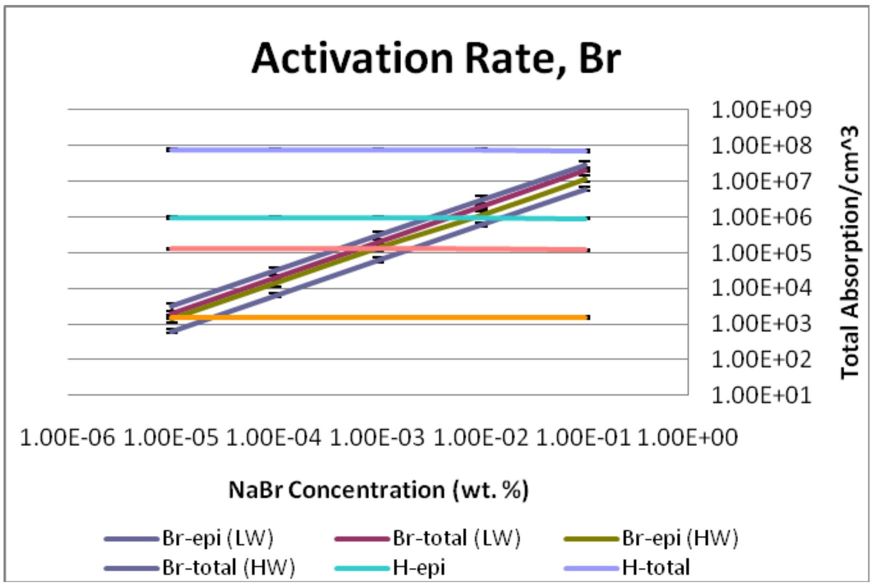

Figure 16, neutron activation rate of Br in light water and heavy water

In addition, within statistical uncertainties there was no difference in the activation rates for the Cl when heavy water was substituted for light water in figure 15; but such result was not repeated for Br. Comparison made in figure 17 revealed a 50%~100% higher activation rate for Br in heavy water solution than in light water. Also note, in both light water and heavy water, epithermal neutron activation rate accounted for about 30%~45% of the total activation rate. All these results are likely due to Br's smaller neutron cross section compared to that of hydrogen and chlorine.

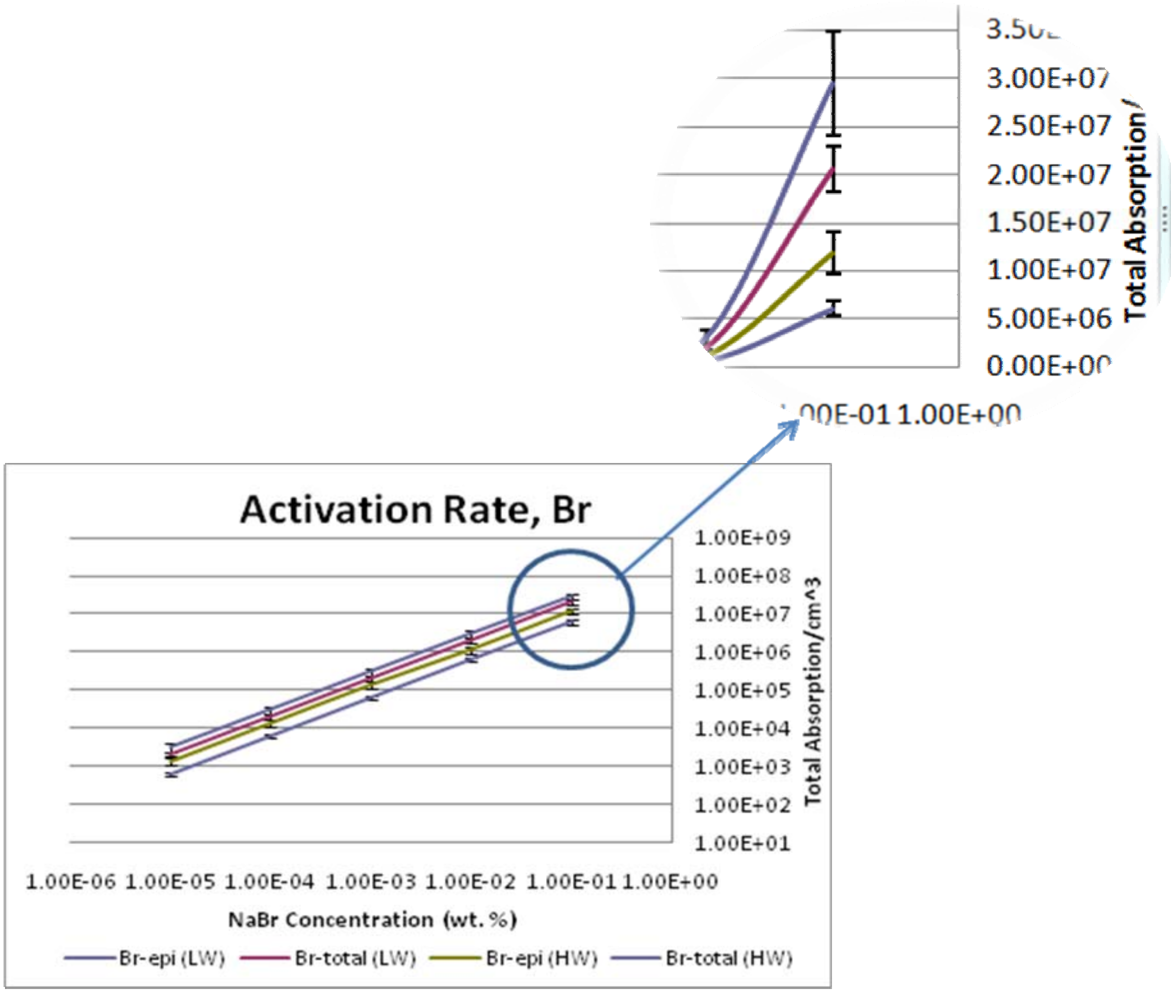

Figure 17, Comparison for neutron activation rate of Br in light water and heavy water

For neutron activation rate of Cl with cadmium shield, figure 18 showed that the thermal activation rate of Cl had no significant difference in light water and heavy water solution; epithermal activation rate, on the other hand, has a 25% higher rate in heavy water than in light water. Note that epithermal neutron activation rate now only was about one order of magnitude lower than thermal neutron activation rate.

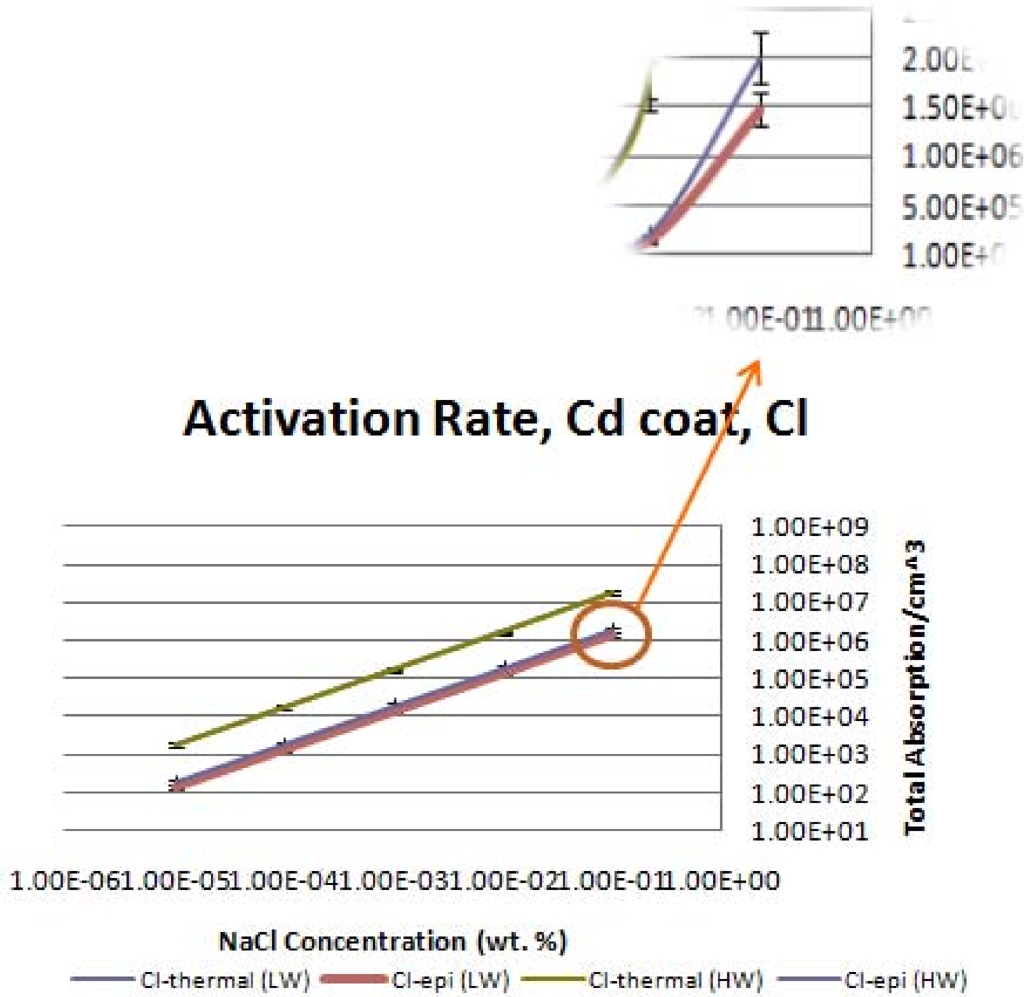

Figure 18, neutron activation rate of Cl with Cd shielding in light water and heavy water

A direct comparison of Cl's neutron activation rate with and without the presence of cadmium shielding was plotted in figure 19 for light water, and figure 20 for heavy water. Note the use of cadmium shielding reduced the epithermal neutron activation rate by 90%, while epithermal neutron activation rate was statistically unchanged.

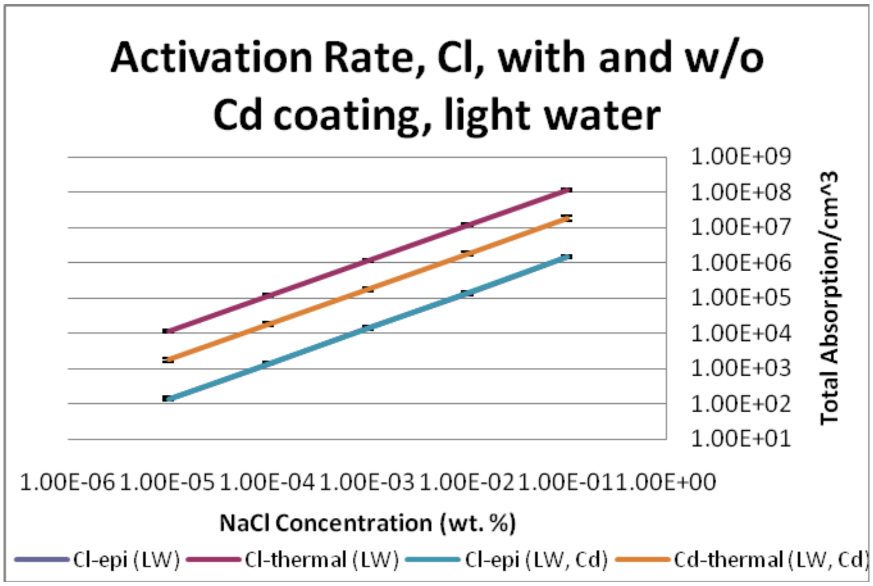

Figure 19, comparison of neutron activation rate of Cl with and without Cd shielding in light water

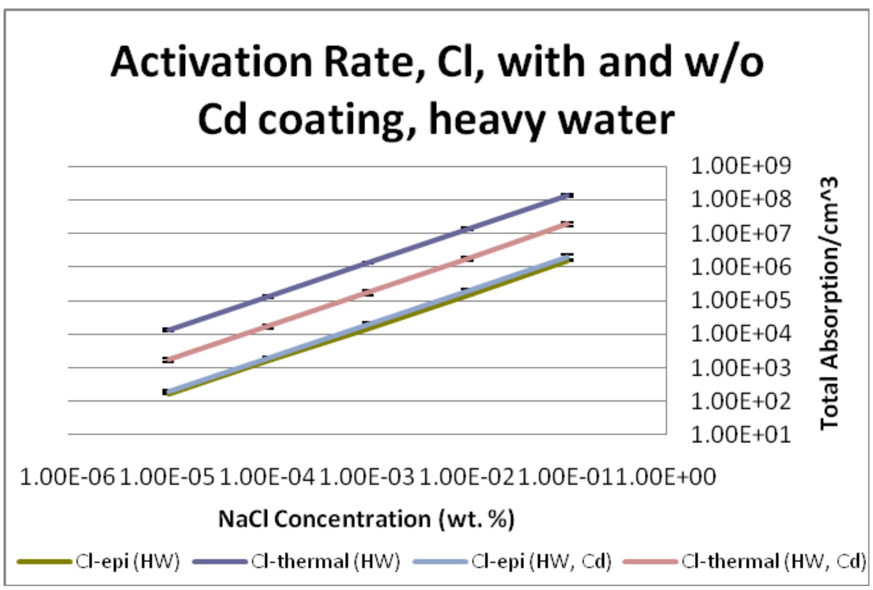

Figure 20, comparison of neutron activation rate of Cl with and without Cd shielding in heavy water

The result in figure 21 for Br with cadmium shielding was more interesting. For both light water and heavy water solution, the thermal neutron activation rates of Br dropped for about 90%; and both were virtually the same. Now, the thermal neutron activation rate for Br in both light water and heavy water was about 15~20% of epithermal neutron activation rate. In addition, the epithermal neutron activation rate for Br in light water solution went up 40% with no statistically significant change in the heavy water solution; however, the heavy water solution still had a 35% higher Br epithermal neutron activation rate than did the light water solution.

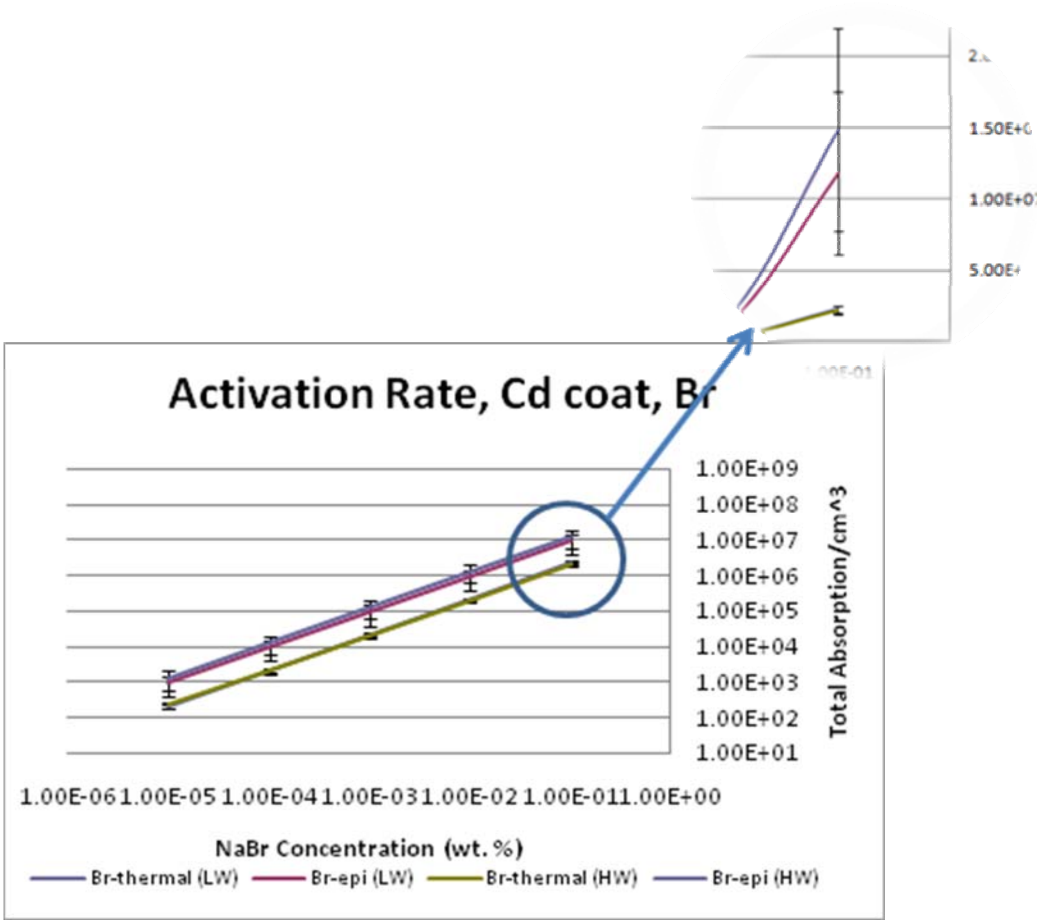

Figure 21, neutron activation rate of Br with Cd shielding in light water and heavy water

It is possible that the higher cross section of the light water effectively 'shields' the Cl and Br by absorbing neutrons in light water. It is also possible that the hydrogen ions downscattered higher energy neutrons in light water, therefore leading to a greater thermalization of epithermal neutrons that did pass through the Cd; these thermalized neutrons were subsequently more likely to be absorbed by the surrounding Cd. It is more likely that hydrogen within the sample vials competed against Br with thermal & epithermal neutron for activation. In the heavy water solution, this effect was not observed and the Br activation rate was considerably higher.

Neutron Activation Analysis

Due to the tight reactor time schedule, the first batch of sample of NaCl was tested through thermal and epithermal neutron analysis on May 5th. The detailed experimental data analysis will be done in the next stage of this study.

Conclusion

In the absence of cadmium, the simulation did not find consistent discrepancy of neutron activation rate between light water and heavy water solution from the hygrogen shielding effect. In the presence of cadmium, a higher activation rate (~25%) in the heavy water solution compared to light water solution was observed, which was likely the same discrepency encountered by Dr. Landsberger.

This phenomenon is likely due to the thermalization and absorption of epithermal neutrons of hydrogen from water solution. The next stage of the study will simulate the neutron activation rate of selected isotopes of Cl-35, Br-81 & Br-79 separately in the sample (which follows the natural abundance) to compare more directly with experimental results. In additon, more experimental neutron activation data would be collected to repeat and verify this simulation observation.

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Appendix

Tables

Table A Atomic Number Density

Table B Activation Rate with and without cadmium

MCNPX Simulation Code

Short code with surface source

Long code with TRIGA deck

Table A, Number Density Calculation for Select Elements

Light Water Solution

	1.00E-05	0.01%	0.10%	1%	10%
NaCl	1.00E-05	1.00E-04	1.00E-03	1.00E-02	1.00E-01
Density (g/cm^3)	1	1	1	1.005	1.07
Nd (water)	3.34147E+22	3.34147E+22	3.34147E+22	3.3246E+22	3.21784E+22
Nd (O)	3.34147E+22	3.34147E+22	3.34147E+22	3.3246E+22	3.21784E+22
Nd (H)	6.68295E+22	6.68295E+22	6.68295E+22	6.6492E+22	6.43568E+22
Nd (Na, Cl)	1.03012E+17	1.03012E+18	1.03012E+19	1.03527E+20	1.10222E+21
scale factor:	4.36E+14				
Nd (H)	2.91E+13	2.91E+13	2.91E+13	2.90E+13	2.81E+13
Nd (Na, Cl)	4.49E+07	4.49E+08	4.49E+09	4.51E+10	4.81E+11

Heavy Water Solution

NaCl	1.00E-05	1.00E-04	1.00E-03	1.00E-02	1.00E-01
Density (g/cm^3)	1.1056	1.1056	1.1056	1.1056	1.17
Nd (heavy water)	3.32121E+22	3.32121E+22	3.32121E+22	3.288E+22	3.1632E+22
Nd (O)	3.32121E+22	3.32121E+22	3.32121E+22	3.288E+22	3.1632E+22
Nd (D)	6.64243E+22	6.64243E+22	6.64243E+22	6.576E+22	6.32641E+22
Nd (Na, Cl)	1.1389E+17	1.1389E+18	1.1389E+19	1.1389E+20	1.20524E+21
scale factor:	4.36E+14				
Nd (D)	2.90E+13	2.90E+13	2.90E+13	2.87E+13	2.76E+13
Nd (Na, Cl)	4.97E+07	4.97E+08	4.97E+09	4.97E+10	5.25E+11

Light Water Solution

	1.00E-05	0.01%	0.10%	1%	10%
NaBr	1.00E-05	1.00E-04	1.00E-03	1.00E-02	1.00E-01
Density (g/cm^3)	1	1	1	1.005	1.07
Nd (water)	3.34147E+22	3.34147E+22	3.34147E+22	3.3246E+22	3.21784E+22
Nd (O)	3.34147E+22	3.34147E+22	3.34147E+22	3.3246E+22	3.21784E+22
Nd (H)	6.68295E+22	6.68295E+22	6.68295E+22	6.6492E+22	6.43568E+22
Nd (Na, Br)	5.85068E+16	5.85068E+17	5.85068E+18	5.87993E+19	6.26023E+20
scale factor:	4.36E+14				
Nd (H)	2.91E+13	2.91E+13	2.91E+13	2.90E+13	2.81E+13
Nd (Na, Br)	2.55E+07	2.55E+08	2.55E+09	2.56E+10	2.73E+11

Heavy Water Solution

NaBr	1.00E-05	1.00E-04	1.00E-03	1.00E-02	1.00E-01
Density (g/cm^3)	1.1056	1.1056	1.1056	1.1056	1.17
Nd (heavy water)	3.32121E+22	3.32121E+22	3.32121E+22	3.288E+22	3.1632E+22
Nd (O)	3.32121E+22	3.32121E+22	3.32121E+22	3.288E+22	3.1632E+22
Nd (D)	6.64243E+22	6.64243E+22	6.64243E+22	6.576E+22	6.32641E+22
Nd (Na, Br)	6.46851E+16	6.46851E+17	6.46851E+18	6.46851E+19	6.8453E+20
scale factor:	4.36E+14				
Nd (D)	2.90E+13	2.90E+13	2.90E+13	2.87E+13	2.76E+13
Nd (Na, Br)	2.82E+07	2.82E+08	2.82E+09	2.82E+10	2.98E+11

Table B, Activation Rate for Selected Elements

With Cd Coating

Br

	activation rate									activation probablity per atom								
L.W.	thermal	error %	error	epi	error %	error	total	error %	error	thermal	error %	error	epi	error %	error	total	error %	error
concen.	Br																	
1.00E-05	2.11E+02	1.18E-01	2.50E+01	9.16E+02	4.74E-01	4.34E+02	1.13E+03	1.18E-01	1.33E+02	3.61E-15	1.18E-01	4.27E-16	1.57E-14	4.74E-01	7.42E-15	1.93E-14	1.18E-01	2.27E-15
0.01%	2.11E+03	1.18E-01	2.50E+02	9.16E+03	4.74E-01	4.34E+03	1.13E+04	1.18E-01	1.33E+03	3.61E-15	1.18E-01	4.27E-16	1.57E-14	4.74E-01	7.42E-15	1.93E-14	1.18E-01	2.27E-15
0.10%	2.11E+04	1.18E-01	2.50E+03	9.16E+04	4.74E-01	4.34E+04	1.13E+05	1.18E-01	1.33E+04	3.62E-15	1.18E-01	4.27E-16	1.57E-14	4.74E-01	7.42E-15	1.93E-14	1.18E-01	2.27E-15
1%	2.12E+05	1.18E-01	2.51E+04	9.17E+05	4.74E-01	4.35E+05	1.13E+06	1.18E-01	1.33E+05	3.61E-15	1.18E-01	4.27E-16	1.56E-14	4.74E-01	7.40E-15	1.92E-14	1.18E-01	2.27E-15
10%	2.26E+06	1.18E-01	2.67E+05	9.53E+06	4.81E-01	4.59E+06	1.18E+07	1.18E-01	1.39E+06	3.61E-15	1.18E-01	4.26E-16	1.52E-14	4.81E-01	7.33E-15	1.88E-14	1.18E-01	2.23E-15
	H																	
1.00E-05	1.15E+07	1.18E-01	1.35E+06	1.01E+06	1.10E-01	1.11E+05	1.25E+07	1.18E-01	1.47E+06	1.72E-16	1.18E-01	2.03E-17	1.51E-17	1.10E-01	1.66E-18	1.87E-16	1.18E-01	2.21E-17
0.01%	1.15E+07	1.18E-01	1.35E+06	1.01E+06	1.10E-01	1.11E+05	1.25E+07	1.18E-01	1.47E+06	1.72E-16	1.18E-01	2.03E-17	1.51E-17	1.10E-01	1.66E-18	1.87E-16	1.18E-01	2.21E-17
0.10%	1.15E+07	1.18E-01	1.35E+06	1.01E+06	1.10E-01	1.11E+05	1.25E+07	1.18E-01	1.47E+06	1.72E-16	1.18E-01	2.03E-17	1.51E-17	1.10E-01	1.66E-18	1.87E-16	1.18E-01	2.21E-17
1%	1.14E+07	1.18E-01	1.35E+06	1.01E+06	1.10E-01	1.11E+05	1.24E+07	1.18E-01	1.47E+06	1.72E-16	1.18E-01	2.03E-17	1.51E-17	1.10E-01	1.66E-18	1.87E-16	1.18E-01	2.21E-17
10%	1.10E+07	1.18E-01	1.31E+06	9.78E+05	1.10E-01	1.08E+05	1.20E+07	1.18E-01	1.42E+06	1.72E-16	1.18E-01	2.03E-17	1.52E-17	1.10E-01	1.67E-18	1.87E-16	1.18E-01	2.21E-17

	activation rate									activation probablity per atom								
H. W.	thermal	error %	error	epi	error %	error	total	error %	error	thermal	error %	error	epi	error %	error	total	error %	error
	Br																	
1.00E-05	2.20E+02	1.45E-01	3.18E+01	1.30E+03	4.63E-01	6.02E+02	1.52E+03	1.45E-01	2.20E+02	3.40E-15	1.45E-01	4.92E-16	2.01E-14	4.63E-01	9.31E-15	2.35E-14	1.45E-01	3.40E-15
0.01%	2.02E+03	1.45E-01	2.92E+02	1.32E+04	4.63E-01	6.11E+03	1.52E+04	1.45E-01	2.20E+03	3.12E-15	1.45E-01	4.52E-16	2.04E-14	4.63E-01	9.44E-15	2.35E-14	1.45E-01	3.40E-15
0.10%	2.02E+04	1.45E-01	2.92E+03	1.32E+05	4.63E-01	6.11E+04	1.52E+05	1.45E-01	2.20E+04	3.12E-15	1.45E-01	4.52E-16	2.04E-14	4.63E-01	9.44E-15	2.35E-14	1.45E-01	3.40E-15
1%	2.02E+05	1.45E-01	2.92E+04	1.31E+06	4.66E-01	6.09E+05	1.51E+06	1.45E-01	2.18E+05	3.11E-15	1.45E-01	4.50E-16	2.01E-14	4.66E-01	9.37E-15	2.32E-14	1.45E-01	3.36E-15
10%	2.17E+06	1.44E-01	3.11E+05	1.27E+07	4.80E-01	6.08E+06	1.48E+07	1.44E-01	2.13E+06	3.16E-15	1.44E-01	4.55E-16	1.85E-14	4.80E-01	8.88E-15	2.17E-14	1.44E-01	3.12E-15
	D																	
1.00E-05	1.60E+04	1.45E-01	2.31E+03	1.10E+03	1.29E-01	1.41E+02	1.70E+04	1.45E-01	2.47E+03	2.40E-19	1.45E-01	3.48E-20	1.65E-20	1.29E-01	2.12E-21	2.57E-19	1.45E-01	3.71E-20
0.01%	1.51E+04	1.45E-01	2.18E+03	2.00E+03	1.29E-01	2.57E+02	1.70E+04	1.45E-01	2.47E+03	2.27E-19	1.45E-01	3.28E-20	3.00E-20	1.29E-01	3.87E-21	2.57E-19	1.45E-01	3.71E-20
0.10%	1.51E+04	1.45E-01	2.18E+03	1.99E+03	1.29E-01	2.57E+02	1.70E+04	1.45E-01	2.47E+03	2.27E-19	1.45E-01	3.28E-20	3.00E-20	1.29E-01	3.87E-21	2.57E-19	1.45E-01	3.71E-20
1%	1.49E+04	1.45E-01	2.16E+03	1.97E+03	1.29E-01	2.54E+02	1.69E+04	1.45E-01	2.44E+03	2.26E-19	1.45E-01	3.28E-20	3.00E-20	1.29E-01	3.86E-21	2.56E-19	1.45E-01	3.71E-20
10%	1.45E+04	1.44E-01	2.09E+03	1.89E+03	1.28E-01	2.43E+02	1.64E+04	1.44E-01	2.36E+03	2.29E-19	1.44E-01	3.30E-20	2.99E-20	1.28E-01	3.83E-21	2.59E-19	1.44E-01	3.73E-20

Cl

	activation rate									activation probablity per atom								
L.W.	thermal	error %	error	epi	error %	error	total	error %	error	thermal	error %	error	epi	error %	error	total	error %	error
	Cl																	
1.00E-05	1.79E+03	1.18E-01	2.12E+02	1.42E+02	1.40E-01	1.98E+01	1.93E+03	1.40E-01	2.70E+02	1.74E-14	1.18E-01	2.06E-15	1.38E-15	1.40E-01	1.92E-16	1.88E-14	1.40E-01	2.62E-15
0.01%	1.79E+04	1.18E-01	2.12E+03	1.42E+03	1.11E-01	1.57E+02	1.93E+04	1.11E-01	2.14E+03	1.74E-14	1.18E-01	2.06E-15	1.38E-15	1.11E-01	1.53E-16	1.88E-14	1.11E-01	2.08E-15
0.10%	1.79E+05	1.18E-01	2.12E+04	1.42E+04	1.11E-01	1.57E+03	1.93E+05	1.11E-01	2.14E+04	1.74E-14	1.18E-01	2.06E-15	1.37E-15	1.11E-01	1.52E-16	1.88E-14	1.11E-01	2.08E-15
1%	1.80E+06	1.18E-01	2.13E+05	1.43E+05	1.11E-01	1.58E+04	1.94E+06	1.11E-01	2.15E+05	1.74E-14	1.18E-01	2.06E-15	1.38E-15	1.11E-01	1.53E-16	1.88E-14	1.11E-01	2.08E-15
10%	1.86E+07	1.16E-01	2.15E+06	1.48E+06	1.08E-01	1.60E+05	2.01E+07	1.08E-01	2.17E+06	1.69E-14	1.16E-01	1.95E-15	1.34E-15	1.08E-01	1.46E-16	1.82E-14	1.08E-01	1.98E-15
	H																	
1.00E-05	1.15E+07	1.18E-01	1.35E+06	1.01E+06	1.10E-01	1.11E+05	1.25E+07	1.10E-01	1.37E+06	1.72E-16	1.18E-01	2.03E-17	1.51E-17	1.10E-01	1.66E-18	1.87E-16	1.10E-01	2.05E-17
0.01%	1.15E+07	1.18E-01	1.35E+06	1.01E+06	1.10E-01	1.11E+05	1.25E+07	1.10E-01	1.37E+06	1.72E-16	1.18E-01	2.03E-17	1.51E-17	1.10E-01	1.66E-18	1.87E-16	1.10E-01	2.05E-17
0.10%	1.15E+07	1.18E-01	1.35E+06	1.01E+06	1.10E-01	1.11E+05	1.25E+07	1.10E-01	1.37E+06	1.72E-16	1.18E-01	2.03E-17	1.51E-17	1.10E-01	1.66E-18	1.87E-16	1.10E-01	2.05E-17
1%	1.14E+07	1.18E-01	1.35E+06	1.01E+06	1.10E-01	1.11E+05	1.24E+07	1.10E-01	1.37E+06	1.72E-16	1.18E-01	2.03E-17	1.51E-17	1.10E-01	1.66E-18	1.87E-16	1.10E-01	2.06E-17
10%	1.07E+07	1.16E-01	1.24E+06	9.53E+05	1.08E-01	1.02E+05	1.17E+07	1.08E-01	1.25E+06	1.67E-16	1.16E-01	1.93E-17	1.48E-17	1.08E-01	1.59E-18	1.82E-16	1.08E-01	1.95E-17

	activation rate									activation probablity per atom								

H. W.	thermal	error %	error	epi	error %	error	total	error %	error	thermal	error %	error	epi	error %	error	total	error %	error
	Cl																	
1.00E-05	1.72E+03	1.45E-01	2.49E+02	1.94E+02	1.31E-01	2.55E+01	1.91E+03	1.31E-01	2.50E+02	1.51E-14	1.45E-01	2.18E-15	1.70E-15	1.31E-01	2.23E-16	1.68E-14	1.31E-01	2.20E-15
0.01%	1.72E+04	1.45E-01	2.49E+03	1.94E+03	1.31E-01	2.55E+02	1.91E+04	1.31E-01	2.50E+03	1.51E-14	1.45E-01	2.18E-15	1.70E-15	1.31E-01	2.23E-16	1.68E-14	1.31E-01	2.20E-15
0.10%	1.72E+05	1.45E-01	2.49E+04	1.94E+04	1.31E-01	2.55E+03	1.91E+05	1.31E-01	2.50E+04	1.51E-14	1.45E-01	2.18E-15	1.70E-15	1.31E-01	2.23E-16	1.68E-14	1.31E-01	2.20E-15
1%	1.71E+06	1.45E-01	2.49E+05	1.93E+05	1.31E-01	2.54E+04	1.91E+06	1.31E-01	2.50E+05	1.51E-14	1.45E-01	2.18E-15	1.70E-15	1.31E-01	2.23E-16	1.68E-14	1.31E-01	2.20E-15
10%	1.86E+07	1.48E-01	2.75E+06	2.00E+06	1.35E-01	2.70E+05	2.06E+07	1.35E-01	2.77E+06	1.54E-14	1.48E-01	2.28E-15	1.66E-15	1.35E-01	2.23E-16	1.70E-14	1.35E-01	2.29E-15
	D																	
1.00E-05	1.51E+04	1.45E-01	2.18E+03	2.00E+03	1.29E-01	2.57E+02	1.70E+04	1.29E-01	2.19E+03	2.27E-19	1.45E-01	3.28E-20	3.01E-20	1.29E-01	3.87E-21	2.57E-19	1.29E-01	3.30E-20
0.01%	1.51E+04	1.45E-01	2.18E+03	2.00E+03	1.29E-01	2.57E+02	1.70E+04	1.29E-01	2.19E+03	2.27E-19	1.45E-01	3.28E-20	3.01E-20	1.29E-01	3.87E-21	2.57E-19	1.29E-01	3.30E-20
0.10%	1.49E+04	1.45E-01	2.16E+03	2.15E+03	1.29E-01	2.77E+02	1.70E+04	1.29E-01	2.19E+03	2.24E-19	1.45E-01	3.25E-20	3.24E-20	1.29E-01	4.17E-21	2.57E-19	1.29E-01	3.30E-20
1%	1.49E+04	1.45E-01	2.15E+03	1.97E+03	1.29E-01	2.54E+02	1.69E+04	1.29E-01	2.17E+03	2.26E-19	1.45E-01	3.27E-20	2.99E-20	1.29E-01	3.85E-21	2.56E-19	1.29E-01	3.30E-20
10%	1.47E+04	1.48E-01	2.17E+03	1.86E+03	1.32E-01	2.45E+02	1.65E+04	1.32E-01	2.18E+03	2.32E-19	1.48E-01	3.43E-20	2.93E-20	1.32E-01	3.87E-21	2.61E-19	1.32E-01	3.45E-20

Without Cd Coating

Br

	activation rate									activation probablity per atom								
L.W.	thermal	error %	error	epi	error %	error	total	error %	error	thermal	error %	error	epi	error %	error	total	error %	error
	Br																	
1.00E-05	1.39E+03	7.13E-02	9.92E+01	6.37E+02	1.33E-01	8.46E+01	2.03E+03	1.33E-01	2.69E+02	2.38E-14	7.13E-02	1.70E-15	1.09E-14	1.33E-01	1.45E-15	3.47E-14	1.33E-01	4.60E-15
0.01%	1.39E+04	7.13E-02	9.92E+02	6.37E+03	1.33E-01	8.46E+02	2.03E+04	1.33E-01	2.69E+03	2.38E-14	7.13E-02	1.70E-15	1.09E-14	1.33E-01	1.45E-15	3.47E-14	1.33E-01	4.60E-15
0.10%	1.39E+05	7.13E-02	9.90E+03	6.37E+04	1.33E-01	8.45E+03	2.03E+05	1.33E-01	2.69E+04	2.37E-14	7.13E-02	1.69E-15	1.09E-14	1.33E-01	1.44E-15	3.46E-14	1.33E-01	4.60E-15
1%	1.39E+06	7.11E-02	9.85E+04	6.34E+05	1.31E-01	8.27E+04	2.02E+06	1.31E-01	2.64E+05	2.36E-14	7.11E-02	1.68E-15	1.08E-14	1.31E-01	1.41E-15	3.44E-14	1.31E-01	4.48E-15
10%	1.45E+07	6.98E-02	1.01E+06	6.08E+06	1.16E-01	7.05E+05	2.05E+07	1.16E-01	2.38E+06	2.31E-14	6.98E-02	1.61E-15	9.71E-15	1.16E-01	1.13E-15	3.28E-14	1.16E-01	3.80E-15
	H																	
1.00E-05	7.54E+07	7.13E-02	5.37E+06	9.52E+05	7.05E-02	6.71E+04	7.64E+07	7.05E-02	5.39E+06	1.13E-15	7.13E-02	8.04E-17	1.43E-17	7.05E-02	1.00E-18	1.14E-15	7.05E-02	8.06E-17
0.01%	7.55E+07	7.13E-02	5.38E+06	9.52E+05	7.05E-02	6.71E+04	7.64E+07	7.05E-02	5.39E+06	1.13E-15	7.13E-02	8.06E-17	1.43E-17	7.05E-02	1.00E-18	1.14E-15	7.05E-02	8.06E-17
0.10%	7.54E+07	7.13E-02	5.38E+06	9.52E+05	7.05E-02	6.71E+04	7.65E+07	7.05E-02	5.39E+06	1.13E-15	7.13E-02	8.05E-17	1.43E-17	7.05E-02	1.00E-18	1.15E-15	7.05E-02	8.07E-17
1%	7.47E+07	7.11E-02	5.31E+06	9.50E+05	7.03E-02	6.68E+04	7.56E+07	7.03E-02	5.31E+06	1.12E-15	7.11E-02	7.98E-17	1.43E-17	7.03E-02	1.00E-18	1.14E-15	7.03E-02	7.99E-17
10%	7.08E+07	6.99E-02	4.95E+06	9.13E+05	6.90E-02	6.30E+04	7.17E+07	6.90E-02	4.95E+06	1.10E-15	6.99E-02	7.69E-17	1.42E-17	6.90E-02	9.80E-19	1.12E-15	6.90E-02	7.69E-17

	activation rate									activation probablity per atom								
H. W.	thermal	error %	error	epi	error %	error	total	error %	error	thermal	error %	error	epi	error %	error	total	error %	error
	Br																	
1.00E-05	1.70E+03	5.88E-02	9.97E+01	1.40E+03	2.30E-01	3.23E+02	3.10E+03	2.30E-01	7.14E+02	2.62E-14	5.88E-02	1.54E-15	2.17E-14	2.30E-01	5.00E-15	4.79E-14	2.30E-01	1.10E-14
0.01%	1.70E+04	5.88E-02	9.97E+02	1.41E+04	2.30E-01	3.24E+03	3.10E+04	2.30E-01	7.14E+03	2.62E-14	5.88E-02	1.54E-15	2.18E-14	2.30E-01	5.01E-15	4.80E-14	2.30E-01	1.10E-14
0.10%	1.71E+05	6.01E-02	1.03E+04	1.41E+05	2.29E-01	3.23E+04	3.12E+05	2.29E-01	7.15E+04	2.64E-14	6.01E-02	1.59E-15	2.18E-14	2.29E-01	4.99E-15	4.82E-14	2.29E-01	1.11E-14
1%	1.93E+06	5.87E-02	1.13E+05	1.17E+06	2.32E-01	2.71E+05	3.10E+06	2.32E-01	7.18E+05	2.97E-14	5.87E-02	1.74E-15	1.80E-14	2.32E-01	4.17E-15	4.77E-14	2.32E-01	1.11E-14
10%	1.76E+07	5.83E-02	1.03E+06	1.19E+07	1.84E-01	2.20E+06	2.96E+07	1.84E-01	5.45E+06	2.57E-14	5.83E-02	1.50E-15	1.74E-14	1.84E-01	3.21E-15	4.32E-14	1.84E-01	7.96E-15
	D																	
1.00E-05	1.26E+05	5.88E-02	7.43E+03	1.53E+03	5.81E-02	8.89E+01	1.28E+05	5.81E-02	7.43E+03	1.90E-18	5.88E-02	1.12E-19	2.30E-20	5.81E-02	1.34E-21	1.93E-18	5.81E-02	1.12E-19
0.01%	1.26E+05	5.88E-02	7.43E+03	1.53E+03	5.81E-02	8.89E+01	1.28E+05	5.81E-02	7.43E+03	1.90E-18	5.88E-02	1.12E-19	2.30E-20	5.81E-02	1.34E-21	1.93E-18	5.81E-02	1.12E-19
0.10%	1.27E+05	6.01E-02	7.66E+03	1.50E+03	5.95E-02	8.93E+01	1.29E+05	5.95E-02	7.67E+03	1.92E-18	6.01E-02	1.15E-19	2.26E-20	5.95E-02	1.34E-21	1.94E-18	5.95E-02	1.16E-19
1%	1.25E+05	5.87E-02	7.33E+03	1.50E+03	5.80E-02	8.70E+01	1.26E+05	5.80E-02	7.33E+03	1.90E-18	5.87E-02	1.11E-19	2.28E-20	5.80E-02	1.32E-21	1.92E-18	5.80E-02	1.11E-19
10%	1.18E+05	5.83E-02	6.90E+03	1.51E+03	5.76E-02	8.72E+01	1.20E+05	5.76E-02	6.90E+03	1.87E-18	5.83E-02	1.09E-19	2.39E-20	5.76E-02	1.38E-21	1.89E-18	5.76E-02	1.09E-19

Cl

	activation rate	activation probablity per atom

L.W.	thermal	error %	error	epi	error %	error	total	error %	error	thermal	error %	error	epi	error %	error	total	error %	error
	Cl																	
1.00E-05	1.18E+04	7.15E-02	8.44E+02	1.41E+02	7.08E-02	1.00E+01	1.19E+04	7.08E-02	8.45E+02	1.15E-13	7.15E-02	8.19E-15	1.37E-15	7.08E-02	9.71E-17	1.16E-13	7.08E-02	8.21E-15
0.01%	1.18E+05	7.15E-02	8.43E+03	1.36E+03	7.08E-02	9.60E+01	1.19E+05	7.08E-02	8.44E+03	1.14E-13	7.15E-02	8.18E-15	1.32E-15	7.08E-02	9.32E-17	1.16E-13	7.08E-02	8.19E-15
0.10%	1.18E+06	7.15E-02	8.43E+04	1.44E+04	7.08E-02	1.02E+03	1.19E+06	7.08E-02	8.45E+04	1.14E-13	7.15E-02	8.18E-15	1.39E-15	7.08E-02	9.86E-17	1.16E-13	7.08E-02	8.20E-15
1%	1.18E+07	7.17E-02	8.46E+05	1.34E+05	7.10E-02	9.51E+03	1.19E+07	7.10E-02	8.47E+05	1.13E-13	7.17E-02	8.13E-15	1.29E-15	7.10E-02	9.14E-17	1.15E-13	7.10E-02	8.14E-15
10%	1.17E+08	7.10E-02	8.30E+06	1.44E+06	7.02E-02	1.01E+05	1.18E+08	7.02E-02	8.30E+06	1.06E-13	7.10E-02	7.54E-15	1.31E-15	7.02E-02	9.19E-17	1.08E-13	7.02E-02	7.55E-15
	H																	
1.00E-05	7.55E+07	7.13E-02	5.38E+06	9.40E+05	7.05E-02	6.63E+04	7.64E+07	7.05E-02	5.39E+06	1.13E-15	7.13E-02	8.05E-17	1.41E-17	7.05E-02	9.92E-19	1.14E-15	7.05E-02	8.06E-17
0.01%	7.54E+07	7.13E-02	5.37E+06	9.30E+05	7.05E-02	6.56E+04	7.63E+07	7.05E-02	5.38E+06	1.13E-15	7.13E-02	8.04E-17	1.39E-17	7.05E-02	9.82E-19	1.14E-15	7.05E-02	8.05E-17
0.10%	7.54E+07	7.13E-02	5.37E+06	1.02E+06	7.05E-02	7.16E+04	7.64E+07	7.05E-02	5.39E+06	1.13E-15	7.13E-02	8.05E-17	1.52E-17	7.05E-02	1.07E-18	1.14E-15	7.05E-02	8.06E-17
1%	7.49E+07	7.15E-02	5.35E+06	9.40E+05	7.07E-02	6.65E+04	7.58E+07	7.07E-02	5.36E+06	1.13E-15	7.15E-02	8.05E-17	1.41E-17	7.07E-02	1.00E-18	1.14E-15	7.07E-02	8.06E-17
10%	6.74E+07	7.08E-02	4.77E+06	8.60E+05	7.00E-02	6.02E+04	6.83E+07	7.00E-02	4.78E+06	1.05E-15	7.08E-02	7.41E-17	1.34E-17	7.00E-02	9.35E-19	1.06E-15	7.00E-02	7.43E-17

	activation rate									activation probablity per atom								
H. W.	thermal	error %	error	epi	error %	error	total	error %	error	thermal	error %	error	epi	error %	error	total	error %	error
	Cl																	
1.00E-05	1.32E+04	6.96E-02	9.19E+02	1.70E+02	6.89E-02	1.17E+01	1.34E+04	6.89E-02	9.21E+02	1.16E-13	6.96E-02	8.07E-15	1.49E-15	6.89E-02	1.03E-16	1.17E-13	6.89E-02	8.09E-15
0.01%	1.32E+05	6.96E-02	9.19E+03	1.70E+03	6.96E-02	1.18E+02	1.34E+05	6.96E-02	9.31E+03	1.16E-13	6.96E-02	8.07E-15	1.49E-15	6.96E-02	1.04E-16	1.17E-13	6.96E-02	8.17E-15
0.10%	1.34E+06	7.23E-02	9.72E+04	1.50E+04	7.16E-02	1.07E+03	1.36E+06	7.16E-02	9.73E+04	1.18E-13	7.23E-02	8.53E-15	1.32E-15	7.16E-02	9.43E-17	1.19E-13	7.16E-02	8.54E-15
1%	1.34E+07	7.23E-02	9.68E+05	1.48E+05	7.16E-02	1.06E+04	1.35E+07	7.16E-02	9.69E+05	1.18E-13	7.23E-02	8.50E-15	1.30E-15	7.16E-02	9.30E-17	1.19E-13	7.16E-02	8.51E-15
10%	1.33E+08	6.87E-02	9.12E+06	1.58E+06	6.80E-02	1.07E+05	1.34E+08	6.80E-02	9.14E+06	1.10E-13	6.87E-02	7.54E-15	1.31E-15	6.80E-02	8.88E-17	1.11E-13	6.80E-02	7.55E-15
	D																	
1.00E-05	1.16E+05	6.93E-02	8.04E+03	1.54E+03	6.84E-02	1.05E+02	1.18E+05	6.84E-02	8.04E+03	1.75E-18	6.93E-02	1.21E-19	2.32E-20	6.84E-02	1.58E-21	1.77E-18	6.84E-02	1.21E-19
0.01%	1.16E+05	6.93E-02	8.04E+03	1.54E+03	6.84E-02	1.05E+02	1.18E+05	6.84E-02	8.04E+03	1.75E-18	6.93E-02	1.21E-19	2.32E-20	6.84E-02	1.58E-21	1.77E-18	6.84E-02	1.21E-19
0.10%	1.18E+05	7.20E-02	8.49E+03	1.57E+03	7.11E-02	1.12E+02	1.19E+05	7.11E-02	8.49E+03	1.78E-18	7.20E-02	1.28E-19	2.37E-20	7.11E-02	1.69E-21	1.80E-18	7.11E-02	1.28E-19
1%	1.16E+05	7.20E-02	8.37E+03	1.55E+03	7.11E-02	1.10E+02	1.18E+05	7.11E-02	8.37E+03	1.77E-18	7.20E-02	1.27E-19	2.35E-20	7.11E-02	1.67E-21	1.79E-18	7.11E-02	1.27E-19
10%	1.05E+05	6.84E-02	7.18E+03	1.50E+03	6.76E-02	1.01E+02	1.07E+05	6.76E-02	7.20E+03	1.66E-18	6.84E-02	1.13E-19	2.37E-20	6.76E-02	1.60E-21	1.68E-18	6.76E-02	1.14E-19

Short Code with Surface Source

```
surface source
c ---------------------------------
c Tube cell for my test (Alex Zhou 2009)
c ----------------------------------
 9001 9924 -1.17 -9001        $ solution inside container
 9002 99 -.93 -9002 +9001   $ container of polyethylene
 9101 9990 -8.65 -9101 +9002 $ Cd foil
 9012 1 -1   -111 +121 -9010 +9101  $ cell of surface source
c
c ------------
c Outside world
c ------------
 2999 0 +111: -121: +9010

c surface card
c ------------------------------------
c upper and lower bounds
c --------------------------------------
 111 pz +3.3 $ Upper cap of surface source
 121 PZ -1.7 $ Lower cap of surface source
c
c ---------------------------------
c Tube surface for my test (Alex Zhou 2009)
c ----------------------------------
```

```
9001 rcc +19.59102 +11.31062 0.05 0 0 1.5 0.5 $sample space inside container
9002 rcc +19.59102 +11.31062 0 0 0 1.6 0.55 $container of polyethylene
9101 rcc +19.59102 +11.31062 -.01 0 0 1.62 0.56 $Cd foil
9010 c/z +19.59102 +11.31062 1.5 $ surface source bound

c data card
c ---------------------------------
c Tube material for my test (Alex Zhou 2009)
c ----------------------------------
m1   1001 0.66667
     8016 0.33333
m99  1001 2
     6012 1
MT99 POLY.60t $ CH2, polyethylene
m9920 1002 -.20000  $ .001% NaBr heavy water solution
      8016 -.79999
      11023 -2.24E-6
      35081 -3.88E-6
      35079 -3.88E-6
m9921 1002 -.2000  $ .01% NaBr heavy water solution
      8016 -.7999
      11023 -2.24E-5
      35081 -3.88E-5
      35079 -3.88E-5
m9922 1002 -.200  $ .1% NaBr heavy water solution
      8016 -.799
      11023 -2.24E-4
```

```
       35081 -3.88E-4
       35079 -3.88E-4
 m9923 1002 -.20  $ 1% NaBr heavy water solution
       8016 -.79
       11023 -2.24E-3
       35081 -3.88E-3
       35079 -3.88E-3
 m9924 1002 -.2  $ .001% NaBr heavy water solution
       8016 -.7
       11023 -2.24E-2
       35081 -3.88E-2
       35079 -3.88E-2
 m9992 2001 .667 $ water
       8016 .333
 m9990 48000 1 $ cd
 MT9992 hwtr.60c
 m9993 11023 1 $ Na
 m9994 17000 1 $ Cl
 m9999 35079 .5069 $ Br
       35081 .4931
 m9995 1001 1 $ H
 m9996 1002 1 $ D2 heavey water
 MT9  POLY.60t
c
 mode n p
c phys:p 100 0 0 0 1 -102 $ -102, Analog sampling, models only, multigroup +
line emission
 imp:n 1 3r 0
```

```
 imp:p 1 3r 0
c energy band: thermal, epithermal, and fast
 ssr old -9010 -111 121
 E4 1E-6 1e-3 1
 F4:n 9001
 FM4 (2.98e+11 9999 -2) (2.76e+13 9996 -2)
 FC4
print
```

(The long code with TRIGA deck takes 67 pages; to save paper, I will submit the electronic version of the code upon request)

Long Code with TRIGA Deck

```
c---------------UT TRIGA -Core Model -07/12/2007 --------------
c
c -----------------------------------------------------------
c Beginning of Cell Card Specification
c -----------------------------------------------------------
c ----------
c Core region
c ----------
 1099 1 -1.0 -202 +206
     -231 +232 -233 +234 -235 +236
     -241 +242 -243 +244 -245 +246
     +5000 +5001 +5002 +5003 +5004 +5005 +5006 +5007 +5008 +5009
     +5010 +5011 +5012 +5013 +5014 +5015 +5016 +5017 +5018 +5019
     +5020 +5021 +5022 +5023 +5024 +5025 +5026 +5027 +5028 +5029
     +5030 +5031 +5032 +5033 +5034 +5035 +5036 +5037 +5038
       +5041 +5042 +5043 +5044 +5045 +5046    +5048 +5049
     +5050 +5051 +5052 +5053 +5054 +5055 +5056 +5057 +5058 +5059
     +5060 +5061 +5062         +5066 +5067 +5068 +5069
     +5070 +5071 +5072       +5075 +5076 +5077 +5078 +5079
     +5080 +5081 +5082 +5083 +5084 +5085 +5086 +5087 +5088 +5089
     +5090 +5091 +5092       +5095 +5096 +5097 +5098 +5099
     +5100    +5102 +5103 +5104 +5105 +5106 +5107 +5108 +5109
     +5110    +5112 +5113 +5114       +5117 +5118  +5119
     +5120
```

```
     +1963 +1964 +1965 +1966          $ Mapping experiment
     +5101
     +1940 $ 6L
     +5047 +5073 +5074 $ Elements in 3L
     +2000 +2001 +2002 +2003 +2004 +2005 +2006
c    +5111 +5115
c    +5039 +5040 +5063 +5064 +5065 +5093 +5094 $ Elements in 6L
c    +961 $ 3L
c    +5118 $ PNT
c
 520 0 -201 +207 -1963 fill=101 (10) $ Flux mapping water cells
 521 0 -201 +207 -1964 fill=101 (11)
 522 0 -201 +207 -1965 fill=101 (12)
 523 0 -201 +207 -1966 fill=101 (13)
c
 600 0 -110 +120 -5000 fill=82 (100) $ A1 Fuel & graphite elements
 601 0 -110 +120 -5001 fill=8 (101) $ B1 Control rods
 602 0 -110 +120 -5002 fill=8 (102) $ B2
 603 0 -110 +120 -5003 fill=8 (103) $ B3
 604 0 -110 +120 -5004 fill=8 (104) $ B4
 605 0 -110 +120 -5005 fill=8 (105) $ B5
 606 0 -110 +120 -5006 fill=8 (106) $ B6
 607 0 -110 +120 -5007 fill=7 (107) $ C1 -CR(T)
 608 0 -110 +120 -5008 fill=8 (108) $ C2
 609 0 -110 +120 -5009 fill=8 (109) $ C3
 610 0 -110 +120 -5010 fill=8 (110) $ C4
 611 0 -110 +120 -5011 fill=8 (111) $ C5
```

612 0 -110 +120 -5012 fill=8 (112) $ C6

613 0 -110 +120 -5013 fill=9 (113) $ C7 -CR(R)

614 0 -110 +120 -5014 fill=8 (114) $ C8

615 0 -110 +120 -5015 fill=8 (115) $ C9

616 0 -110 +120 -5016 fill=8 (116) $ C10

617 0 -110 +120 -5017 fill=8 (117) $ C11

618 0 -110 +120 -5018 fill=8 (118) $ C12

619 0 -110 +120 -5019 fill=8 (119) $ D1

620 0 -110 +120 -5020 fill=8 (120) $ D2

621 0 -110 +120 -5021 fill=8 (121) $ D3

622 0 -110 +120 -5022 fill=8 (122) $ D4

623 0 -110 +120 -5023 fill=8 (123) $ D5

624 0 -110 +120 -5024 fill=9 (124) $ D6 -CR(S)

625 0 -110 +120 -5025 fill=8 (125) $ D7

626 0 -110 +120 -5026 fill=8 (126) $ D8

627 0 -110 +120 -5027 fill=8 (127) $ D9

628 0 -110 +120 -5028 fill=8 (128) $ D10

629 0 -110 +120 -5029 fill=8 (129) $ D11

630 0 -110 +120 -5030 fill=8 (130) $ D12

631 0 -110 +120 -5031 fill=8 (131) $ D13

632 0 -110 +120 -5032 fill=9 (132) $ D14 -CR(S)

633 0 -110 +120 -5033 fill=8 (133) $ D15

634 0 -110 +120 -5034 fill=8 (134) $ D16

635 0 -110 +120 -5035 fill=8 (135) $ D17

636 0 -110 +120 -5036 fill=8 (136) $ D18

637 0 -110 +120 -5037 fill=8 (137) $ E1

638 0 -110 +120 -5038 fill=8 (138) $ E2

```
c 639 0 -110 +120 -5039 fill=8 (139) $ E3
c 640 0 -110 +120 -5040 fill=8 (140) $ E4
 641 0 -110 +120 -5041 fill=8 (141) $ E5
 642 0 -110 +120 -5042 fill=8 (142) $ E6
 643 0 -110 +120 -5043 fill=8 (143) $ E7
 644 0 -110 +120 -5044 fill=8 (144) $ E8
 645 0 -110 +120 -5045 fill=8 (145) $ E9
 646 0 -110 +120 -5046 fill=8 (146) $ E10
 647 0 -110 +120 -5047 fill=8 (147) $ E11
 648 0 -110 +120 -5048 fill=8 (148) $ E12
 649 0 -110 +120 -5049 fill=8 (149) $ E13
 650 0 -110 +120 -5050 fill=8 (150) $ E14
 651 0 -110 +120 -5051 fill=8 (151) $ E15
 652 0 -110 +120 -5052 fill=8 (152) $ E16
 653 0 -110 +120 -5053 fill=8 (153) $ E17
 654 0 -110 +120 -5054 fill=8 (154) $ E18
 655 0 -110 +120 -5055 fill=8 (155) $ E19
 656 0 -110 +120 -5056 fill=8 (156) $ E20
 657 0 -110 +120 -5057 fill=8 (157) $ E21
 658 0 -110 +120 -5058 fill=8 (158) $ E22
 659 0 -110 +120 -5059 fill=8 (159) $ E23
 660 0 -110 +120 -5060 fill=8 (160) $ E24
 661 0 -110 +120 -5061 fill=8 (161) $ F1
 662 0 -110 +120 -5062 fill=8 (162) $ F2
c 663 0 -110 +120 -5063 fill=8 (163) $ F3
c 664 0 -110 +120 -5064 fill=8 (164) $ F4
c 665 0 -110 +120 -5065 fill=8 (165) $ F5
```

666 0 -110 +120 -5066 fill=8 (166) $ F6

667 0 -110 +120 -5067 fill=8 (167) $ F7

668 0 -110 +120 -5068 fill=8 (168) $ F8

669 0 -110 +120 -5069 fill=8 (169) $ F9

670 0 -110 +120 -5070 fill=8 (170) $ F10

671 0 -110 +120 -5071 fill=8 (171) $ F11

672 0 -110 +120 -5072 fill=8 (172) $ F12

673 0 -110 +120 -5073 fill=8 (173) $ F13

674 0 -110 +120 -5074 fill=8 (174) $ F14

675 0 -110 +120 -5075 fill=8 (175) $ F15

676 0 -110 +120 -5076 fill=8 (176) $ F16

677 0 -110 +120 -5077 fill=8 (177) $ F17

678 0 -110 +120 -5078 fill=8 (178) $ F18

679 0 -110 +120 -5079 fill=8 (179) $ F19

680 0 -110 +120 -5080 fill=8 (180) $ F20

681 0 -110 +120 -5081 fill=8 (181) $ F21

682 0 -110 +120 -5082 fill=8 (182) $ F22

683 0 -110 +120 -5083 fill=8 (183) $ F23

684 0 -110 +120 -5084 fill=8 (184) $ F24

685 0 -110 +120 -5085 fill=8 (185) $ F25

686 0 -110 +120 -5086 fill=8 (186) $ F26

687 0 -110 +120 -5087 fill=8 (187) $ F27

688 0 -110 +120 -5088 fill=8 (188) $ F28

689 0 -110 +120 -5089 fill=8 (189) $ F29

690 0 -110 +120 -5090 fill=8 (190) $ F30

691 0 -110 +120 -5091 fill=6 (191) $ G2

692 0 -110 +120 -5092 fill=8 (192) $ G3

```
c 693 0 -110 +120 -5093 fill=8 (193) $ G4
c 694 0 -110 +120 -5094 fill=8 (194) $ G5
 695 0 -110 +120 -5095 fill=8 (195) $ G6
 696 0 -110 +120 -5096 fill=8 (196) $ G8
 697 0 -110 +120 -5097 fill=8 (197) $ G9
 698 0 -110 +120 -5098 fill=8 (198) $ G10
 699 0 -110 +120 -5099 fill=8 (199) $ G11
 700 0 -110 +120 -5100 fill=8 (200) $ G12
 701 0 -110 +120 -5101 fill=8 (201) $ G14
 702 0 -110 +120 -5102 fill=8 (202) $ G15
 703 0 -110 +120 -5103 fill=6 (203) $ G16
 704 0 -110 +120 -5104 fill=8 (204) $ G17
 705 0 -110 +120 -5105 fill=8 (205) $ G18
 706 0 -110 +120 -5106 fill=6 (206) $ G20
 707 0 -110 +120 -5107 fill=8 (207) $ G21
 708 0 -110 +120 -5108 fill=8 (208) $ G22
 709 0 -110 +120 -5109 fill=8 (209) $ G23
 710 0 -110 +120 -5110 fill=6 (210) $ G24
c 711 0 -110 +120 -5111 fill=8 (211) $ G26
 712 0 -110 +120 -5112 fill=8 (212) $ G27
 713 0 -110 +120 -5113 fill=8 (213) $ G28
 714 0 -110 +120 -5114 fill=8 (214) $ G29
c 715 0 -110 +120 -5115 fill=8 (215) $ G30
c 716 0 -110 +120 -5116 fill=8 (216) $ G32 $ Location of source
 717 0 -110 +120 -5117 fill=6 (217) $ G33 $ Graphite
c 718 0 -110 +120 -5118 fill=8 (218) $ G34 $ Location of PNT
 719 0 -110 +120 -5119 fill=6 (219) $ G35 $ Graphite
```

```
 720 0 -110 +120 -5120 fill=6 (220) $ G36
c
 750 0 -110 +120 -1940 fill=96 (50) $ Sleeve irradiator
c
c 751 0 -110 +120 -961 fill=40 (20) $ 3L(Pb) irradiator
c
c 751 0 -110 +120 -961 fill=45 (20) $ 3L(Cd) irradiator
c
c 752 0 -110 +120 -5118 fill=30 (218) $ tPNT irradiator
c
c 752 0 -110 +120 -5118 fill=35 (218) $ ePNT irradiator
c
c ----------------------
c Lower grid plate region
c ----------------------
 1 2 -2.7 -206 +207
       -211 +212 -213 +214 -215 +216
       -221 +222 -223 +224 -225 +226
      +5000 +5001 +5002 +5003 +5004 +5005 +5006 +5007 +5008 +5009
      +5010 +5011 +5012 +5013 +5014 +5015 +5016 +5017 +5018 +5019
      +5020 +5021 +5022 +5023 +5024 +5025 +5026 +5027 +5028 +5029
      +5030 +5031 +5032 +5033 +5034 +5035 +5036 +5037 +5038
        +5041 +5042 +5043 +5044 +5045 +5046 +5048 +5049
      +5050 +5051 +5052 +5053 +5054 +5055 +5056 +5057 +5058 +5059
      +5060 +5061 +5062 +5066 +5067 +5068 +5069
      +5070 +5071 +5072 +5075 +5076 +5077 +5078 +5079
      +5080 +5081 +5082 +5083 +5084 +5085 +5086 +5087 +5088 +5089
```

```
      +5090 +5091 +5092 +5095 +5096 +5097 +5098 +5099
      +5100 +5102 +5103 +5104 +5105 +5106 +5107 +5108 +5109
      +5110 +5112 +5113 +5114 +5117 +5118 +5119
      +5120
      +5101
      +1963 +1964 +1965 +1966 $ Mapping experiment
      +1940 $ 6L
      +5047 +5073 +5074 $ Elements in 3L
c +5111 +5115
c +5039 +5040 +5063 +5064 +5065 +5093 +5094 $ Elements in 6L
c +961 $ 3L
c +5118 $ PNT
c
c ----------------------
c  Upper grid plate region
c ----------------------
 2 2 -2.7 -203 -201 +202
      +5000 +5001 +5002 +5003 +5004 +5005 +5006 +5007 +5008 +5009
      +5010 +5011 +5012 +5013 +5014 +5015 +5016 +5017 +5018 +5019
      +5020 +5021 +5022 +5023 +5024 +5025 +5026 +5027 +5028 +5029
      +5030 +5031 +5032 +5033 +5034 +5035 +5036 +5037 +5038
        +5041 +5042 +5043 +5044 +5045 +5046 +5048 +5049
      +5050 +5051 +5052 +5053 +5054 +5055 +5056 +5057 +5058 +5059
      +5060 +5061 +5062         +5066 +5067 +5068 +5069
      +5070 +5071 +5072      +5075 +5076 +5077 +5078 +5079
      +5080 +5081 +5082 +5083 +5084 +5085 +5086 +5087 +5088 +5089
      +5090 +5091 +5092 +5095      +5096 +5097 +5098 +5099
```

```
      +5100 +5102 +5103 +5104 +5105 +5106 +5107 +5108 +5109
      +5110 +5112 +5113 +5114 +5117 +5118 +5119
      +5120
      +5101
      +1963 +1964 +1965 +1966 $ Mapping experiment
      +1940 $ 6L
      +5047 +5073 +5074 $ Elements in 3L
c     +5111 +5115
c     +5039 +5040 +5063 +5064 +5065 +5093 +5094 $ Elements in 6L
c     +961 $ 3L
c     +5118 $ PNT
c
c ---------------------
c Reactor core structure
c ---------------------
c Inner core shroud
c ----------------
 10 2 -2.7 -300 +302 -303 +202 $ Alignment ring
 11 2 -2.7 -300 -202 +352 $ Alignment ring
      (+231: -232: +241: -242:
       +233: -234: +243: -244:
       +235: -236: +245: -246)
 12 2 -2.7 +305 -306 +307 $ Shroud load ring
      (-311 +312 -321 +322
       -313 +314 -323 +324
       -315 +316 -325 +326)
 13 2 -2.7 -301 -352 +304 $ Alignment ring
```

```
    (+331: -332: +341: -342:
     +333: -334: +343: -344:
     +335: -336: +345: -346)
14 2 -2.7 +231 -331 -233 +236 $ Reflector plate
     -352 +306
15 2 -2.7 -232 +332 +234 -235 $ Reflector plate
     -352 +306
16 2 -2.7 +241 -341 -343 -345 $ Reflector, bp3
     -352 +306 +363
17 2 -2.7 -242 +342 +344 +346 $ Reflector plate
     -352 +306
18 2 -2.7 +233 -333 -331 -343 $ Reflector plate
     -352 +306
19 2 -2.7 -234 +334 +332 +344 $ Reflector plate
     -352 +306
20 2 -2.7 +235 -335 +332 -345 $ Reflector plate
     -352 +306
21 2 -2.7 -236 +336 -331 +346 $ Reflector plate
     -352 +306
22 2 -2.7 +243 -343 -241 -233 $ Reflector plate
     -352 +306
23 2 -2.7 -244 +344 +242 +234 $ Reflector plate
     -352 +306
24 2 -2.7 +245 -345 -241 -235 $ Reflector plate
     -352 +306
25 2 -2.7 -246 +346 +242 +236 $ Reflector plate
     -352 +306
```

```
 26 2 -2.7 +241 -363 +364 -360 $ Reflector BP3
 27 2 -2.7 -361 +362 -100 $ Reflector BP1&5
c
c -------------------------------
c Reflector outer shroud structure
c -------------------------------
 30 2 -2.7 -355 +361 $ Reflector cylin
        -350 +351 -352 +353
 31 2 -2.7 +355 +363 $ Reflector cylin
        -350 +351 -352 +353
 32 2 -2.7 -370 +371 -372 +373 $ Cylinder, top
 33 2 -2.7 -374 -375 +376 $ Cylinder, bot
       (+331: -332: +341: -342:
        +333: -334: +343: -344:
       +335: -336: +345: -346)
 34 2 -2.7 -370 +374 -375 +377 $ Reflector edge ring
 35 2 -2.7 -352 -371 +380 +381 $ Reflector RSR unit
 36 2 -2.7 -380 +300 +381 -382 $ Reflector RSR unit
 37 2 -2.7 -352 +301 -300 +381 $ Reflector RSR unit
 38 1 -1.0 +370 -351 -377 +120 $ Edge ring error
c
c ---------------------------
c Reflector graphite moderator
c ---------------------------
 40 4 -1.60 -400 +401 -402 +403 $ Reflector graphite
 41 4 -1.60 -400 -403 +375 -404 +361
       (+411: -412: +421: -422:
```

```
  +413: -414: +423: -424:
  +415: -416: +425: -426)
  #(-361 +405) $ Graphite, bp1&5
42 4 -1.60 (-400 -403 +375 +404 +363
 (+411: -412: +421: -422:
  +413: -414: +423: -424:
  +415: -416: +425: -426))
 #(-406 +408) #(-407 +409) $ Graphite, bp3
43 8 -1.15e-3 (+371 -351 -373 +403) #40 $ Graphite void?????
44 8 -1.15e-3 (-351 -403 +375 -404 +361
 (+331: -332: +341: -342:
  +333: -334: +343: -344:
  +335: -336: +345: -346)) #41 $ graphite void
45 8 -1.15e-3 (-351 -403 +375 +404 +363
 (+331: -332: +341: -342:
  +333: -334: +343: -344:
  +335: -336: +345: -346)) #42 $ graphite void
46 8 -1.15e-3 -304 +403 -301
 (+331: -332: +341: -342:
  +333: -334: +343: -344:
  +335: -336: +345: -346) $ graphite void
47 8 -1.15e-3 +301 -371 +403 -381 $ graphite void
c
c -----------------
c Pool coolant water
c -----------------
50 1 -1.0 -203 +201 -110 $ Above upper grid plate
```

```
      +5000 +5001 +5002 +5003 +5004 +5005 +5006 +5007 +5008 +5009
      +5010 +5011 +5012 +5013 +5014 +5015 +5016 +5017 +5018 +5019
      +5020 +5021 +5022 +5023 +5024 +5025 +5026 +5027 +5028 +5029
      +5030 +5031 +5032 +5033 +5034 +5035 +5036 +5037 +5038
      +5041 +5042 +5043 +5044 +5045 +5046 +5048 +5049
      +5050 +5051 +5052 +5053 +5054 +5055 +5056 +5057 +5058 +5059
      +5060 +5061 +5062 +5066 +5067 +5068 +5069
      +5070 +5071 +5072 +5075 +5076 +5077 +5078 +5079
      +5080 +5081 +5082 +5083 +5084 +5085 +5086 +5087 +5088 +5089
      +5090 +5091 +5092 +5095 +5096 +5097 +5098 +5099
      +5100 +5102 +5103 +5104 +5105 +5106 +5107 +5108 +5109
      +5110 +5112 +5113 +5114 +5117 +5118 +5119
      +5120
      +5101
      +1940 $ 6L
      +5047 +5073 +5074 $ Elements in 3L
c     +5111 +5115
c     +5039 +5040 +5063 +5064 +5065 +5093 +5094 $ Elements in 6L
c     +961 $ 3L
c     +5118 $ PNT
c
 51 1 -1.0 +203 -302 +202 -110 $ Upper gridplate
 52 1 -1.0 +302 -300 +303 -110 $ Upper gridplate
 53 1 -1.0 -305 -306 +307 $ Lower gridplate
      +5000 +5001 +5002 +5003 +5004 +5005 +5006 +5007 +5008 +5009
      +5010 +5011 +5012 +5013 +5014 +5015 +5016 +5017 +5018 +5019
      +5020 +5021 +5022 +5023 +5024 +5025 +5026 +5027 +5028 +5029
```

```
        +5030 +5031 +5032 +5033 +5034 +5035 +5036 +5037 +5038
        +5041 +5042 +5043 +5044 +5045 +5046 +5048 +5049
        +5050 +5051 +5052 +5053 +5054 +5055 +5056 +5057 +5058 +5059
        +5060 +5061 +5062 +5066 +5067 +5068 +5069
        +5070 +5071 +5072 +5075 +5076 +5077 +5078 +5079
        +5080 +5081 +5082 +5083 +5084 +5085 +5086 +5087 +5088 +5089
        +5090 +5091 +5092 +5095 +5096 +5097 +5098 +5099
        +5100 +5102 +5103 +5104 +5105 +5106 +5107 +5108 +5109
        +5110 +5112 +5113 +5114 +5117 +5118 +5119
        +5120
        +5101
        +1940 $ 6L
        +5047 +5073 +5074 $ Elements in 3L
c       +5111 +5115
c       +5039 +5040 +5063 +5064 +5065 +5093 +5094 $ Elements in 6L
c       +961 $ 3L
c       +5118 $ PNT
c
 54 1 -1.0 -307 +120 $ Lower gridplate
       (-311 +312 -321 +322
        -313 +314 -323 +324
        -315 +316 -325 +326)
       +5000 +5001 +5002 +5003 +5004 +5005 +5006 +5007 +5008 +5009
       +5010 +5011 +5012 +5013 +5014 +5015 +5016 +5017 +5018 +5019
       +5020 +5021 +5022 +5023 +5024 +5025 +5026 +5027 +5028 +5029
       +5030 +5031 +5032 +5033 +5034 +5035 +5036 +5037 +5038
       +5041 +5042 +5043 +5044 +5045 +5046 +5048 +5049
```

```
      +5050 +5051 +5052 +5053 +5054 +5055 +5056 +5057 +5058 +5059
      +5060 +5061 +5062 +5066 +5067 +5068 +5069
      +5070 +5071 +5072 +5075 +5076 +5077 +5078 +5079
      +5080 +5081 +5082 +5083 +5084 +5085 +5086 +5087 +5088 +5089
      +5090 +5091 +5092 +5095 +5096 +5097 +5098 +5099
      +5100 +5102 +5103 +5104 +5105 +5106 +5107 +5108 +5109
      +5110 +5112 +5113 +5114 +5117 +5118 +5119
      +5120
      +5101
      +1940 $ 6L
      +5047 +5073 +5074 $ Elements in 3L
c      +5111 +5115
c      +5039 +5040 +5063 +5064 +5065 +5093 +5094 $ Elements in 6L
c       +961 $ 3L
c      +5118 $ PNT
c
 55 1 -1.0 -207 +306 $ Lower gridplate
      (-231 +232 -241 +242
       -233 +234 -243 +244
      -235 +236 -245 +246)
     +5000 +5001 +5002 +5003 +5004 +5005 +5006 +5007 +5008 +5009
     +5010 +5011 +5012 +5013 +5014 +5015 +5016 +5017 +5018 +5019
     +5020 +5021 +5022 +5023 +5024 +5025 +5026 +5027 +5028 +5029
     +5030 +5031 +5032 +5033 +5034 +5035 +5036 +5037 +5038
     +5041 +5042 +5043 +5044 +5045 +5046 +5048 +5049
     +5050 +5051 +5052 +5053 +5054 +5055 +5056 +5057 +5058 +5059
     +5060 +5061 +5062 +5066 +5067 +5068 +5069
```

```
     +5070 +5071 +5072 +5075 +5076 +5077 +5078 +5079
     +5080 +5081 +5082 +5083 +5084 +5085 +5086 +5087 +5088 +5089
     +5090 +5091 +5092 +5095 +5096 +5097 +5098 +5099
     +5100 +5102 +5103 +5104 +5105 +5106 +5107 +5108 +5109
     +5110 +5112 +5113 +5114 +5117 +5118 +5119
     +5120
     +5101
     +1940 $ 6L
     +5047 +5073 +5074 $ Elements in 3L
c    +5111 +5115
c    +5039 +5040 +5063 +5064 +5065 +5093 +5094 $ Elements in 6L
c     +961 $ 3L
c    +5118 $ PNT
c
 56 1 -1.0 -206 +207 $ Lower gridplate
      (+211: -212: +221: -222:
       +213: -214: +223: -224:
       +215: -216: +225: -226)
      (-231 +232 -241 +242
       -233 +234 -243 +244
       -235 +236 -245 +246)
 57 1 -1.0 -351 +371 +372 -110 $ Upper reflector
 58 1 -1.0 -374 -376 +120 $ Lower reflector
      (+311: -312: +321: -322:
       +313: -314: +323: -324:
       +315: -316: +325: -326)
 59 1 -1.0 +306 -376 $ Lower reflector
```

```
      (+331: -332: +341: -342:
       +333: -334: +343: -344:
       +335: -336: +345: -346)
      (-311 +312 -321 +322
       -313 +314 -323 +324
       -315 +316 -325 +326)
c
c -----------------
c Pool coolant water
c -----------------
 950 8 -1.15e-3 -150 +160 -165
     *TRCL  (-60.00 00.00 00.00 00 90 90 90 00 90) $NP
 951 8 -1.15e-3 -150 +160 -165
     *TRCL ( 57.96 -15.53 00.00 00 90 90 90 00 90) $NPP
 952 8 -1.15e-3 -150 +160 -165
     *TRCL ( 42.43 42.43 00.00 00 90 90 90 00 90) $FC
 60 1 -1.0 +350 -355 +361
       (-100 -110 +120) #950 #951 $ Beam ports 1&5
 61 1 -1.0 +350 +355 +363
       (-100 -110 +120) #950 #952
       #(-406 +408) #(-407 +409) $ Beam ports 2&4
 62 1 -1.0 -363 +364 +360 -100 $ Reflector BP3
 63 1 -1.0 -350 +351 +352 -110 $ Reflector cylinder
 64 1 -1.0 -350 +351 -353 +120 $ Reflector cylinder
 65 1 -1.0 -370 +374 -377 +120 $ Reflector edgering
 66 1 -1.0 +300 -371 +303 -110 $ RSR removal
 67 2 -2.7 +370 -351 -375 +377 $ edge ring error
```

```
 68 2 -2.7 -351 +370 -372 +373 $ edge ring error
c --------------------
c BP2, BP4 structure
c --------------------
 71 2 -2.7 (-406 +430) +350 +355 -100 $ Reflector BP2
 72 2 -2.7 (-407 +440) +350 +355 -100 $ Reflector BP4
c
c ------------
c BP3 structure
c ------------
 73 2 -2.7 +461 -462 -464 $ Reflector BP3
 74 2 -2.7 -463 +464 +461 -100 $ Reflector BP3
 75 1 -1.0 +241 -364 -461 $ Reflector BP3
 76 1 -1.0 +463 -364 +461 -100 $ Reflector BP3
c
c -------------------
c BP1, BP3, BP5 cavity
c -------------------
 77 8 -1.15e-3 +450 -362 -451 $ Reflector BP1
 78 8 -1.15e-3 +462 -464 -453 $ Reflector BP3
 79 8 -1.15e-3 -450 -362 +455
c
c -----------------------------
c BP1, BP2, BP3, BP4, BP5 cavity
c -----------------------------
 81 8 -1.15e-3 +451 -362 -100 #95 VOL=1 $ Reflector BP1
 82 8 -1.15e-3 (-430 +408) +350 -100 #96 VOL=1 $ Reflector BP2
```

```
 83 8 -1.15e-3 +453 -464 -100 #97 VOL=1 $ Reflector BP3
 84 8 -1.15e-3 (-440 +409) +350 -100 #98 VOL=1 $ Reflector BP4
 85 8 -1.15e-3 -455 -362 -100 #99 VOL=1 $ Reflector BP5
c
 95 8 -1.15e-3 -171
 96 8 -1.15e-3 -172
 97 8 -1.15e-3 -173
 98 8 -1.15e-3 -174
 99 8 -1.15e-3 -175
c
c ------------------------------
c Rotary specimen rack (RSR) unit
c ------------------------------
 90 8 -1.15e-3 +300 -303 +352 -371 $ RSR unit
 91 8 -1.15e-3 +300 +304 -352 -380 $ RSR unit
 92 8 -1.15e-3 +300 -304 -380 +382 $ RSR unit
c
c ----------------------------------
c Fill universe for reactor core grid
c ----------------------------------
c Graphite reflector elements, U=6
c -------------------------------
 100 1 -1.0 #101 #102 #103
        #104 #105 #106 u=6
 101 2 -2.7 -623 -609 +206 u=6 $ lower fitting
 102 2 -2.7 -605 -620 +621 u=6 $ end closure
 103 4 -1.60 -605 -621 +622 u=6 $ graphite
```

```
 104 2 -2.7 -605 -622 +623 u=6 $ end closure
 105 2 -2.7 +620 -609 -201 u=6 $ upper fitting
 106 2 -2.7 +605 -607 -620 +623 u=6 $ element clad
c
c ------------------------
c Transient control rod, U=7
c ------------------------
 110 1 -1.0 #111 #112 #113 #114
        #115 #116 #117 u=7
 111 2 -2.7 -500 -510 +511 u=7 $ end plug
 112 2 -2.7 -500 -511 +512 u=7 $ spacer plug
 113 6 -2.52 -500 -512 +513 u=7 $ absorber
 114 2 -2.7 -500 -513 +514 u=7 $ spacer plug
 115 8 -1.15e-3 -500 -514 +515 u=7 $ air follower
 116 3 -7.8 -500 -515 +516 u=7 $ end plug
 117 3 -7.8 +500 -502 -510 +516 u=7 $ element clad
c
c ------------------------------
c Standard triga fuel element, U=8
c ------------------------------
c Temperature in fuel rod assumed 300 C at full power
 120 1 -1.0 #121 #122 #123
        #124 #125 #126
        #127 #128 #129 u=8 $ element clad
 121 3 -7.8 -615 -603 +206 u=8 $ lower fitting
 122 3 -7.8 -600 -610 +611 u=8 $ end closure
 123 4 -1.60 -600 -611 +612 u=8 $ graphite
```

```
 124 5 -6.05 -600 -612 +613 +650 u=8 $ TMP1=4.939E-8 $ fuel
 125 7 -6.49 -650 -612 +613 u=8 $ Zr rod
 126 4 -1.60 -600 -613 +614 u=8 $ graphite
 127 3 -7.8 -600 -614 +615 u=8 $ end closure
 128 3 -7.8 +610 -603 -201 u=8 $ upper fitting
 129 3 -7.8 +600 -602 -610 +615 u=8 $ element clad
c
c --------------------------------------------------
c Fuel follower control rods (reg, shim1, shim2), U=9
c --------------------------------------------------
c Temperature assumed 300 C at full power
 130 1 -1.0 #131 #132 #133 #134 #135
        #136 #137 #138 #139 #140
        #141 #142 #143 u=9
 131 3 -7.8 -505 -520 +521 u=9 $ end plug
 132 8 -1.15e-3 -505 -521 +522 u=9 $ top space
 133 2 -2.7 -505 -522 +523 u=9 $ spacer plug
 134 8 -1.15e-3 -505 -523 +524 u=9 $ void gap
 135 6 -2.52 -505 -524 +525 u=9 $ absorber, inside 505,524; outside 525,
 136 2 -2.7 -505 -525 +526 u=9 $ spacer plug
 137 8 -1.15e-3 -505 -526 +527 u=9 $ void gap
 138 5 -6.05 -505 -527 +528 +550 u=9 $ TMP1=4.939E-8 $ fuel follower
 139 7 -6.49 -550 -527 +528 u=9 $ Zr rod
 140 2 -2.7 -505 -528 +529 u=9 $ spacer plug
 141 8 -1.15e-3 -505 -529 +530 u=9 $ bot space
 142 3 -7.8 -505 -530 +531 u=9 $ end plug
 143 3 -7.8 +505 -507 -520 +531 u=9 $ element clad
```

```
c
c --------------------------------------
c Modifications and experiment components
c --------------------------------------
c Pneumatic transfer system (PTS) without Cd, U=30 -JDB -4/13/2007
c ----------------------------------------------
 300 1 -1.0 #301 #302 #303
        #304 #305 #306
        #307 #308 U=30 $ Water surrounding PTS
 301 2 -2.7 -910 +911 +933 U=30 $ Al transport tube
 302 8 -1.15e-3 -911 +912 +933 U=30 $ Air gap
 303 2 -2.7 -912 +913 +915 U=30 $ Al sample tube
 304 8 -1.15e-3 -913 +915 #308 U=30 $ Sample location
 305 2 -2.7 -910 +934 -933 U=30 $ Al transport tube bottom
 306 2 -2.7 -912 +931 -915 U=30 $ Al sample tube bottom
 307 8 -1.15e-3 +933 -931 -912 U=30 $ Air gap beneath sample tube
 308 8 -1.15e-3 -908 +909 -907 U=30 $ Sample location for tally
c
c -------------------------------------------
c Pneumatic transfer system (PTS) with Cd, U=35 -JDB -4/13/2007
c -------------------------------------------
 350 1 -1.0 #351 #352 #353
        #354 #355 #356
        #357 #358 #359 #360 U=35 $ Water surrounding PTS
 351 2 -2.7 -910 +911 +933 U=35 $ Al transport tube
 352 8 -1.15e-3 -911 +914 +933 U=35 $ Air gap
 353 10 -8.65 -914 +912 +931 U=35 $ Cd liner
```

```
 354 2 -2.7 -912 +913 +915 U=35 $ Al sample tube
 355 8 -1.15e-3 -913 +915 #360 U=35 $ Sample location
 356 2 -2.7 -910 +934 -933 U=35 $ Al transport tube bottom
 357 2 -2.7 -912 +931 -915 U=35 $ Al sample tube bottom
 358 10 -8.65 -914 -931 +932 U=35 $ Cd liner beneath sample
 359 8 -1.15e-3 +933 -932 -914 U=35 $ Air gap beneath sample tube
 360 8 -1.15e-3 -908 +909 -907 U=35 $ Sample location for tally
c
c --------------------------------
c 3-element irradiator with Pb, U=40
c --------------------------------
 400 1 -1.0 #401 #402 #403 #404
        #405 #406 #407 #408
        #409 #410 u=40 $ Water
 401 2 -2.7 -920 +921 -958 +959 u=40 $ Al outer
 402 8 -1.15e-3 -921 +924 -958 +959 u=40 $ Air gap
 403 11 -11.4 -924 +922 -958 +959 u=40 $ Pb liner
 404 2 -2.7 -922 +923 -958 +959 u=40 $ Al liner
 405 8 -1.15e-3 -923 -963 +965 u=40 $ Air in sample location
 406 8 -1.15e-3 -923 -958 +963 u=40 $ Air above sample location
 407 2 -2.7 -962 -957 +958 u=40 $ Upper end cap
 408 2 -2.7 -920 -959 +960 u=40 $ Lower end cap
 409 2 -2.7 -923 -965 +966 u=40
 410 11 -11.4 -923 -966 +959 u=40
c
c --------------------------------
c 3-element irradiator with Cd, U=45
```

```
c --------------------------------
 450 1 -1.0 #451 #452 #453 #454
        #455 #456 #457 #458
        #459 #460 U=45 $ Water
 451 2 -2.7 -920 +921 -958 +959 U=45 $ Al outer
 452 2 -2.7 -922 +923 -958 +959 U=45 $ Al liner
 453 10 -8.65 +922 -924 -958 +959 U=45 $ Cd liner
 454 8 -1.15e-3 -921 +924 -958 +959 U=45 $ Air gap
 455 8 -1.15e-3 -923 -963 +965 U=45 $ Air in sample location
 456 8 -1.15e-3 -923 -958 +963 u=45 $ Air above sample location
 457 2 -2.7 -962 -957 +958 u=45 $ Upper end cap
 458 2 -2.7 -920 -959 +960 u=45 $ Lower end cap
 459 2 -2.7 -923 -965 +966 u=45
 460 10 -8.65 -923 -966 +959 u=45
c
c ----------------------------------
c 3-element irradiator (unlined), U=50
c ----------------------------------
 490 8 -1.15e-3 #491 #492 #493 #494 U=50 $
 491 2 -2.7 -922 +923 -950 +955 U=50 $ T3 can cylinder
 492 2 -2.7 +922 -924 -950 +955 U=50 $ T3 can liner
 493 2 -2.7 -923 +950 -951 U=50 $ T3 can upper
 494 2 -2.7 -923 -955 +956 U=50 $ T3 can lower
c
c ---------------------------------------
c Water cells for mapping experiment, u=101
c ---------------------------------------
```

```
 515 1 -1.0 #516 u=101
 516 1 -1.0 -754 +782 -750 u=101
c
c ----------------------------------------
c Large irradiator with cadmium sleeve, u=96
c ----------------------------------------
 811 1 -1.0   #812 #813 #814 #815
          #816 #817 #818 #819
          #820 #821 #822 u=96 $ Water outside of 7L
c
 812 2 -2.7 -1941 +1942 +1959 -1960 u=96 $ Al clad outer, sleeve
 813 11 -11.4 -1942 +1943 +1959 -1960 u=96 $ Pb liner, sleeve
 814 2 -2.7 -1943 +1944 +1959 -1960 u=96 $ Al clad inner, sleeve
c
 815 2 -2.7 -1945 +1946 -957 +965 u=96 $ Al clad, can
 816 21 -2.7 -1946 +1947 -957 +965 u=96 $ Al-B liner, can
 817 8 -1.15e-3 -1947 -963 +965 u=96 $ Air in sample location, can
 818 8 -1.15e-3 -1947 -958 +963 u=96 $ Air above sample, can
c
 819 2 -2.7 -1941 +1944 -1961 +1960 u=96 $ Upper end fitting, sleeve
 820 2 -2.7 -1941 +1944 -1959 +1956 u=96 $ Lower end fitting, sleeve
c
 821 2 -2.7 -1945 -957 +958 u=96 $ Upper end fitting, can
 822 2 -2.7 -1945 -965 +1956 u=96 $ Lower end fitting, can
c
c --------------
c 1-inch detector
```

```
c --------------
 1740 1 -1.0 #1741 #1742 U=81 $ element clad
 1741 8 -1.15e-3 -638 -639 +640 #1742 U=81
 1742 8 -1.15e-3 -638 -641 +642 U=81 $ flux tally for 1" dia FC
c
c --------------------
c Central thimble (CT), u=82 -JDB
c --------------------
 1750 1 -1.0 #1751 #1752 u=82
 1751 2 -2.7 -442 +443 +207 u=82
 1752 1 -1.0 -446 +447 -445 u=82
c
c --------------------------
c Photon Radial Profile Holes
c --------------------------
 1800 1 -1.0 -2000
 1801 1 -1.0 -2001
 1802 1 -1.0 -2002
 1803 1 -1.0 -2003
 1804 1 -1.0 -2004
 1805 1 -1.0 -2005
 1806 1 -1.0 -2006
c --------------------------------
c Tube cell for my test (Alex Zhou 2009)
c ---------------------------------
 9001 9910 -1 -9001        $ solution inside container
 9002 99 -.93 -9002 +9001   $ container of polyethylene
```

```
c 9012 1 -1   -111 +121 -9010 +9002  $ cell of surface source

 9003 1 -1   -110 +120 -9003 +9002  $ outside container, inside surface 602,
water in between

 9004 2 -2.7  -110 +120 -9004 +9003 $ shell

 9005 1 -1  -110 +120 -5118 +9004 $ out shell

c

c ------------

c Outside world

c ------------

 2999 0 +100: +110: -120

c

c

c below are a few references of surfaces used for the cell

c ----------------------------------------------------------

c 718 0 -110 +120 -5118 fill=8 (218) $ G34 $ Location of PNT

c tr218 +19.59102 +11.31062 0.0 $ G34

c 5118 c/z +19.59102 +11.31062 +1.91135 $ Upper grid plate hole, G34

c

c 9001 rcc +19.59102 +11.31062 0.05 0 0 1.5 0.5 $ sample space inside
container

c 9002 rcc +19.59102 +11.31062 0 0 0 1.6 0.55 $ container of polyethylene

c 9003 c/z +19.59102 +11.31062 +1.816 $ assembly for G34

c 9004 c/z +19.59102 +11.31062 +1.867 $ out shell

c 9010 c/z +19.59102 +11.31062 +1.5 $ surface source bound

c ------------------------------------------------------------

c End of Cell Card Specification

c ------------------------------------------------------------
```

```
c ------------------------------------------------------------
c Beginning of Surface Card Specification
c ------------------------------------------------------------
c Hexagonal cell lattice surfaces
c ------------------------------
 101 PX +2.17678 $ Fuel lattice hex-prism
 102 PX -2.17678 $ Fuel lattice hex-prism
 103 P +1 1.73205 0 +4.35356 $ Fuel lattice hex-prism
 104 P +1 1.73205 0 -4.35356 $ Fuel lattice hex-prism
 105 P -1 1.73205 0 +4.35356 $ Fuel lattice hex-prism
 106 P -1 1.73205 0 -4.35356 $ Fuel lattice hex-prism
 107 CZ +2.51353 $ Maximum lattice diagonal radius
c
 108 py 5.65531
 109 py -5.65531
c
c ----------------------
c Axial and radial domain
c ----------------------
 100 CZ +75
 110 PZ +75 $ Upper bound
 111 pz +3.3 $ Upper cap of surface source
 120 PZ -75 $ Lower bound
 121 PZ -1.7 $ Lower cap of surface source
 150 CZ +5.08 $ Detector Cylinder
 160 PZ +10 $ Detector Lower
 165 PZ +30 $ Detector Upper
```

```
c
 171 s 60.000 -36.000 -6.985 2.5 $ bp1
 172 s 60.000 36.000 -6.985 2.5 $ bp2
 173 s 0.000 70.000 -6.985 2.5 $ bp3
 174 s -60.000 36.000 -6.985 2.5 $ bp4
 175 s -60.000 -36.000 -6.985 2.5 $ bp5
c
c -------------------------------
c Reactor core grid plate surfaces
c -------------------------------
 200 CZ 1.91135 $ Grid plate element holes
 201 PZ +32.3850 $ Upper grid plate region
 202 PZ +30.7975 $ Upper grid plate region
 203 CZ 27.6225 $ Upper grid plate diameter -effective core diameter
 205 CZ 1.5875 $ Grid plate coolant holes
 206 PZ -33.17875 $ Lower grid plate region
 207 PZ -36.35375 $ Lower grid plate region
 211 PX +26.1216 $ Lower grid plate edge
 212 PX -26.1216 $ Lower grid plate edge
 213 P +1 0.57735 0 +29.0240 $ Lower grid plate edge
 214 P +1 0.57735 0 -29.0240 $ Lower grid plate edge
 215 P -1 0.57735 0 +29.0240 $ Lower grid plate edge
 216 P -1 0.57735 0 -29.0240 $ Lower grid plate edge
 221 PY +25.1360 $ Lower grid plate edge
 222 PY -25.1360 $ Lower grid plate edge
 223 P +1 1.73205 0 +52.2432 $ Lower grid plate edge
 224 P +1 1.73205 0 -52.2432 $ Lower grid plate edge
```

```
 225 P -1 1.73205 0 +52.2432 $ Lower grid plate edge
 226 P -1 1.73205 0 -52.2432 $ Lower grid plate edge
 231 PX +26.6700 $ Core shroud inside surface
 232 PX -26.6700 $ Core shroud inside surface
 233 P +1 0.57735 0 +29.2100 $ Core shroud inside surface
 234 P +1 0.57735 0 -29.2100 $ Core shroud inside surface
 235 P -1 0.57735 0 +29.2100 $ Core shroud inside surface
 236 P -1 0.57735 0 -29.2100 $ Core shroud inside surface
 241 PY +25.4000 $ Core shroud inside surface
 242 PY -25.4000 $ Core shroud inside surface
 243 P +1 1.73205 0 +54.9275 $ Core shroud inside surface
 244 P +1 1.73205 0 -54.9275 $ Core shroud inside surface
 245 P -1 1.73205 0 +54.9275 $ Core shroud inside surface
 246 P -1 1.73205 0 -54.9275 $ Core shroud inside surface
c
c ----------------------
c Core structure surfaces
c ----------------------
c Reflector inner shroud
c ---------------------
 300 CZ 30.083125 $ Grid plate alignment ring
 301 CZ 29.765625 $ Grid plate alignment ring
 302 CZ 27.9400 $ Grid plate alignment ring
 303 PZ +33.9725 $ Grid plate alignment ring
 304 PZ +26.3525 $ Grid plate alignment ring
c
c ---------------
```

```
c Shroud load ring
c ---------------
 305 CZ 27.9400 $ Reflector shroud load ring $ 24.7650
 306 PZ -37.30625 $ Reflector shroud load ring
 307 PZ -39.52875 $ Reflector shroud load ring
c
 311 PX +29.2100 $ Reflector shroud support
 312 PX -29.2100 $ Reflector shroud support
 313 P +1 0.57735 0 +32.385 $ Reflector shroud support
 314 P +1 0.57735 0 -32.385 $ Reflector shroud support
 315 P -1 0.57735 0 +32.385 $ Reflector shroud support
 316 P -1 0.57735 0 -32.385 $ Reflector shroud support
 321 PY +27.9400 $ Reflector shroud support
 322 PY -27.9400 $ Reflector shroud support
 323 P +1 1.73205 0 +59.3725 $ Reflector shroud support
 324 P +1 1.73205 0 -59.3725 $ Reflector shroud support
 325 P -1 1.73205 0 +59.3725 $ Reflector shroud support
 326 P -1 1.73205 0 -59.3725 $ Reflector shroud support
c
 331 PX +27.3050 $ Core shroud plate exterior
 332 PX -27.3050 $ Core shroud plate exterior
 333 P +1 0.57735 0 +29.8450 $ Core shroud plate exterior
 334 P +1 0.57735 0 -29.8450 $ Core shroud plate exterior
 335 P -1 0.57735 0 +29.8450 $ Core shroud plate exterior
 336 P -1 0.57735 0 -29.8450 $ Core shroud plate exterior
 341 PY +26.0350 $ Core shroud plate exterior
 342 PY -26.0350 $ Core shroud plate exterior
```

```
 343 P +1 1.73205 0 +56.5150 $ Core shroud plate exterior
 344 P +1 1.73205 0 -56.5150 $ Core shroud plate exterior
 345 P -1 1.73205 0 +56.5150 $ Core shroud plate exterior
 346 P -1 1.73205 0 -56.5150 $ Core shroud plate exterior
c
c ---------------------
c Reflector outer shroud
c ---------------------
 350 CZ +54.76875 $ Reflector outer shroud
 351 CZ +53.49875 $ Reflector outer shroud
 352 PZ +28.8925 $ Outer shroud upper edge
 353 PZ -32.0675 $ Outer shroud lower edge
 355 PY 0.0 $ Core shroud section plane
c
c -------------------
c Reflector beam ports
c -------------------
 360 PY +55.5625 $ Radial penetrating beam port
 361 C/X -35.2552 -6.985 7.62 $ Tangential thru beam port
 362 C/X -35.2552 -6.985 6.9088 $ Tangential thru beam port
 363 C/Y 0.0 -6.985 10.160 $ Radial penetrating beam port
 364 C/Y 0.0 -6.985 9.525 $ Radial penetrating beam port
c
 370 CZ 53.3400 $ Reflector top shroud
 371 CZ 37.4650 $ Reflector top shroud
 372 PZ +29.5275 $ Reflector top shroud
 373 PZ +28.2575 $ Reflector top shroud
```

```
 374 CZ 52.0700 $ Reflector inner shroud base
 375 PZ -27.9400 $ Reflector inner shroud base
 376 PZ -29.5275 $ Reflector inner shroud base
 377 PZ -36.8300 $ Reflector shroud edge ring
c
c --------------------
c RSR experiment system
c --------------------
 380 CZ +37.1475 $ RSR cavity outer ring
 381 PZ +6.9850 $ RSR cavity base
 382 PZ +7.3025 $ RSR cavity base
c
c --------------------------
c Graphite reflector surfaces
c --------------------------
 400 CZ 53.0225 $ Graphite reflector outer radius
 401 CZ 37.7825 $ Graphite reflector inner radius
 402 PZ 27.6225 $ Graphite reflector upper section
 403 PZ 6.3500 $ Graphite reflector section plane
 404 PY -20.32 $ Graphite reflector section plane
 405 PY -35.2552 $ Beam port penetration
c C/Y 0.0 -6.985 10.160 $ Radial penetrating beam port, bp3
c C/X -35.2552 -6.985 7.62 $ Tangential thru beam port, bp1&5
 406 2 CY 7.62 $ Tangential beam port, bp2
 407 4 CY 7.62 $ Radial beam port, bp4
 408 2 PY 0.0 $ Tangential beam port, bp2
 409 4 PY 0.0 $ Radial beam port, bp4
```

```
 411 PX +27.78125 $ Graphite inner surface
 412 PX -27.78125 $ Graphite inner surface
 413 P +1 0.57735 0 +31.00875 $ Graphite inner surface +1
 414 P +1 0.57735 0 -31.00875 $ Graphite inner surface +1
 415 P -1 0.57735 0 +31.00875 $ Graphite inner surface +1
 416 P -1 0.57735 0 -31.00875 $ Graphite inner surface +1
 421 PY +26.431875 $ Graphite inner surface
 422 PY -26.431875 $ Graphite inner surface
 423 P +1 1.73205 0 +57.30875 $ Graphite inner surface +1
 424 P +1 1.73205 0 -57.30875 $ Graphite inner surface +1
 425 P -1 1.73205 0 +57.30875 $ Graphite inner surface +1
 426 P -1 1.73205 0 -57.30875 $ Graphite inner surface +1
c
 430 2 CY 6.9088 $ Tangential beam port, bp2
 440 4 CY 6.9088 $ Radial beam port, bp4
 450 PX 0.0 $ BP1&5 origin
c
c --------------
c Central thimble -JLP
c --------------
 442 CZ 1.50 $ Central thimble guide rod OD
 443 CZ 1.415 $ Central thimble guid rod ID
 444 CZ 1.25 $ Central thimble sample holder OD
 445 CZ 1.185 $ Central thimble sample holder ID
 446 PZ 2.5 $ Central thimble upper sample hodler
 447 PZ -2.5 $ Central thibmle lower sample holder
c beam port tally surfaces bp1&5 and bp3
```

```
 451 PX +10.16 $ BP1
 453 PY +40.90 $ BP3
 455 PX -10.16 $ BP5
c pool structure pipe, bp3
 461 PY +25.600 $ Radial penetrating beam port, bp3
 462 PY +26.235 $ Radial penetrating beam port, bp3
 463 C/Y 0.0 -6.985 7.62 $ Radial penetrating beam port, bp3
 464 C/Y 0.0 -6.985 6.9088 $ Radial penetrating beam port, bp3
c
c -----------------------
c Control element surfaces
c -----------------------
c data for transient rod
 500 CZ 1.5113 $ Control element -absorber surface, radius
 502 CZ 1.5875 $ Control element -clad outer surface
 505 CZ 1.6637 $ Control element -absorber surface, radius
 507 CZ 1.7145 $ Control element -clad outer surface
c
 510 7 PZ +24.765 $ Control element -element plug, end
 511 7 PZ +24.13 $ Control element -magneform plug, upper
 512 7 PZ +19.05 $ Control element -absorber surface,length/2
 513 7 PZ -19.05 $ Control element -absorber surface,length/2
 514 7 PZ -21.59 $ Control element -magneform plug, lower
 515 7 PZ -70.8025 $ Control element -air follower section
 516 7 PZ -72.7075 $ Control element -element plug, end
c
c data for shim 1, 2 & regulating rod
```

```
c
c 517 pz +75 $
c 518 pz -75 $
c 519 cz 1.5875 $ repeat of 502
c 532 cz 1.7145 $ repeat of 507
c
c lower control rod by 10 unit to reach keff=1
c
 520 7 PZ +24.925 $ Control element -element plug, end
 521 7 PZ +21.115 $ Control element -void gap
 522 7 PZ +10.6375 $ Control element -magneform plug, upper
 523 7 PZ +9.3675 $ Control element -void gap
 524 7 PZ +9.05 $ Control element -absorber surface,length/2
 525 7 PZ -29.05 $ Control element -absorber surface,length/2
 526 7 PZ -30.32 $ Control element -magneform plug, lower
 527 7 PZ -30.955 $ Control element -void gap
 528 7 PZ -69.055 $ Control element -fuel follower section
 529 7 PZ -71.595 $ Control element -void gap
 530 7 PZ -84.93 $ Control element -magneform plug, bottom
 531 7 PZ -84.99 $ Control element -element plug, end
c
 550 CZ 0.28575 $ Zirconium rod
c
c ---------------------------------
c Fuel and moderator element surfaces
c ---------------------------------
 600 CZ 1.816 $ Fuel element -fuel region surface, radius
```

```
 602 CZ 1.867 $ Fuel element -clad outer surface
 603 CZ 1.5306 $ Fuel -adapter effective radius, lower
 604 CZ 1.9426 $ Fuel -adapter effective radius, upper
 605 CZ 1.816 $ Graphite element -element surface, radius
 606 CZ 1.867 $ Graphite element -clad outer surface
 607 CZ 1.867 $ Graphite element -clad outer surface
 608 CZ 1.9426 $ Graphite -adapter effective radius, upper
 609 CZ 1.5306 $ Graphite -adapter effective radius, lower
c
 610 PZ +28.5877 $ Fuel element -element end region, upper
 611 PZ +27.7368 $ Fuel element -graphite end region, upper
 612 PZ +19.05 $ Fuel element -fuel surface, length/2
 613 PZ -19.05 $ Fuel element -fuel surface, length/2
 614 PZ -27.7368 $ Fuel element -graphite end region, lower
 615 PZ -28.5877 $ Fuel element -element end region, lower
c
 620 PZ +28.5877 $ Graphite element -element end, upper
 621 PZ +27.7368 $ Graphite element -graphite end, upper
 622 PZ -27.7368 $ Graphite element -graphite end, lower
 623 PZ -28.5877 $ Graphite element -element end, lower
c
 635 PZ 15.24 $ Flux Tally
 636 PZ -15.24 $ Flux Tally
 637 CZ 0.4 $ Flux Tally hole for the KSU detector
 638 CZ 1.27
 639 PZ 7.7851
 640 PZ -7.7851
```

```
 641 PZ 6.35
 642 PZ -6.35
c
 650 CZ 0.28575 $ Zirconium rod
c
 660 CZ 1.5306 $ Element adapter effective radius
 661 CZ 1.867 $ Element clad outer surface
 662 PZ +32.3850 $ Upper grid plate, top
 663 PZ +28.5877 $ Element end region, upper
 664 PZ -28.5877 $ Element end region, lower
 665 PZ -33.17875 $ Lower grid plate, top
 666 cz 1.91135 $ Upper grid plate holes
c
c ------------------------------
c Boundaries for large irradiator
c ------------------------------
 701 PX +8.70712
 703 PX +10.8839
 708 PX +19.59102
 710 PX 21.7678
 712 PX 19.59102
 717 PX 10.8839
 702 P -1 1.73205 0 -26.12136
 704 P -1 1.73205 0 -21.7678
 705 P 1 1.73205 0 4.35356
 706 P -1 1.73205 0 -26.12136
 707 P 1 1.73205 0 8.70712
```

```
 709 P 1 1.73205 0 4.35356
 711 P -1 1.73205 0 -43.5356
 713 P -1 1.73205 0 -47.88916
 714 P 1 1.73205 0 -13.06068
 715 P -1 1.73205 0 -43.5356
 716 P 1 1.73205 0 -17.41424
 718 P 1 1.73205 0 -13.06068
c
c -------------------------
c Reactor core modifications
c -------------------------
c Center tube irradiations
c -----------------------
 900 CZ 1.905 $ Center tube outer radius
 901 CZ 1.69418 $ Center tube inner radius
 905 CZ 1.5 $ Sample radius
 907 PZ +0.5 $ Sample length
 908 CZ 0.5 $ Sample radius (PTS)
 909 PZ -0.5 $ Sample length
c
c ------------------
c PNT tube dimensions
c ------------------
 910 CZ +1.74625 $ Al transport tube outer radius
 911 CZ +1.53543 $ Al transport tube inner radius
 912 CZ +1.11125 $ Al sample tube outer radius
 913 CZ +0.86995 $ Al sample tube inner radius
```

```
 914 CZ +1.16205 $ Cd two layer liner
 915 PZ -2.07645 $ PTS sample stop
 916 PZ -18.89125 $ Cd absorber end
 917 PZ -21.1264591 $ Cd absorber disk, upper edge
 918 PZ -21.17725 $ Cd absorber disk, lower edge
 919 PZ -30.32125 $ PTS bottom section
 931 PZ -2.94775 $ Al sample tube bottom
 932 PZ -2.99855 $ Bottom of Cd liner
 933 PZ -3.37193 $ Top of Al transport tube
 934 PZ -3.58275 $ Bottom of Al transport tube
c
c ---------------------------------
c 3-element irradiator with Cd or Pb
c ---------------------------------
c Reference to lower grid plate -33.17875
 920 CZ +2.38125 $ Al can outer radius
 921 CZ +2.23393 $ Al can inner radius
 922 CZ +2.06375 $ Al sleeve outer radius
 923 CZ +1.93929 $ Al sleeve inner radius
 924 CZ +2.16535 $ Cd liner outer radius
c 930 CZ +0.47625 $ Al structure rod
c 940 PZ -30.xxxx $ Al bearing section
 950 PZ +2.54 $ Al upper end cap
 951 PZ +2.5908 $ Al upper end cap
 955 PZ -2.54 $ Al lower end cap
 956 PZ -2.5908 $ Al lower end cap
c
```

```
 957 pz +99.82125 $ Al upper end cap, top
 958 pz +96.82125 $ Al upper end cap, bottom
 963 pz +30.7975 $ Bottom of upper grid plate
 959 pz -26.19375 $ Al lower end cap, top
 960 pz -31.27385 $ Al lower end cap, bottom
 962 cz +3.00000
c
 961 c/z -15.23746 -8.79856 +3.0099
c
 965 pz -25.55875 $ Top of Al in Al sleeve
 966 pz -26.09215 $ Top of Cd liner in sleeve
 967 pz -26.19375 $ Top of lower end cap
c
c ------------------------
c Large irradiator surfaces
c ------------------------
 1920 cz +4.35385 $ Al can outer radius
 1921 cz +4.19510 $ Al can inner radius
 1922 cz +4.03635 $ Al sleeve outer radius
 1923 cz +3.91189 $ Al sleeve inner radius
 1924 cz +4.13795 $ Cd liner outer radius
 1925 cz +5.08254
c
 1950 pz +32.3850 $ Al upper end cap
 1951 pz +32.22625 $ Al upper end cap
 1955 pz -33.02 $ Al lower end cap
 1956 pz -33.17875 $ Al lower end cap
```

```
c
 1957 pz +58.26125
 1958 pz +58.89625
 1959 pz -30.63875
 1960 pz +60.80125
 1961 pz +63.34125
c
c ------------------------------------------
c Large irradiator surfaces with cadmium sleeve
c ------------------------------------------
 1940 c/z 15.23746 -11.31062 5.27939 $ Center of irradiator
c
 1941 cz 4.91998
 1942 cz 4.60248
 1943 cz 3.81
 1944 cz 3.4925
 1945 cz 3.175
 1946 cz 2.8575
 1947 cz 2.6575
c
c -----------------------------------
c Surfaces for flux mapping with Ni wire -JDB
c -----------------------------------
 1963 c/z 2.17678 -1.2573 +0.16 $ A
 1964 c/z 15.23746 -1.2573 +0.16 $ K
 1965 c/z 19.59102 -1.2573 +0.16 $ L
 1966 c/z 23.94458 -1.2573 +0.16 $ M
```

```
c
 750 cz 0.15875 $ Keep! 7/12/2006
 751 cz 0.16 $ Keep! 7/12/2006
 754 pz 32.385 $ Keep! 7/12/2006
 782 pz -36.35375 $ Keep! 7/12/2006
c
c --------------------------
c Photon Radial Profile Holes
c --------------------------
 2000 s +0.0 +2.51353  +0.0 0.3175
 2001 s +0.0 +5.020706 +0.0 0.3175
 2002 s +0.0 +10.05412 +0.0 0.3175
 2003 s +0.0 +12.56765 +0.0 0.3175
 2004 s +0.0 +17.59470 +0.0 0.3175
 2005 s +0.0 +20.10823 +0.0 0.3175
 2006 s +0.0 +25.0    +0.0 0.3175
c
c ---------------------
c Upper grid plate holes
c ---------------------
 5000 c/z +0.00000 +0.00000 +1.91135 $ Upper grid plate hole, A1
 5001 c/z +4.35356 +0.00000 +1.91135 $ Upper grid plate hole, B1
 5002 c/z +2.17678 -3.76936 +1.91135 $ Upper grid plate hole, B2
 5003 c/z -2.17678 -3.76936 +1.91135 $ Upper grid plate hole, B3
 5004 c/z -4.35356 +0.00000 +1.91135 $ Upper grid plate hole, B4
 5005 c/z -2.17678 +3.76936 +1.91135 $ Upper grid plate hole, B5
 5006 c/z +2.17678 +3.76936 +1.91135 $ Upper grid plate hole, B6
```

5007 c/z +8.70712 +0.00000 +1.91135 $ Upper grid plate hole, C1

5008 c/z +6.53034 -3.76936 +1.91135 $ Upper grid plate hole, C2

5009 c/z +4.35356 -7.54126 +1.91135 $ Upper grid plate hole, C3

5010 c/z -0.00000 -7.54126 +1.91135 $ Upper grid plate hole, C4

5011 c/z -4.35356 -7.54126 +1.91135 $ Upper grid plate hole, C5

5012 c/z -6.53034 -3.76936 +1.91135 $ Upper grid plate hole, C6

5013 c/z -8.70712 +0.00000 +1.91135 $ Upper grid plate hole, C7

5014 c/z -6.53034 +3.76936 +1.91135 $ Upper grid plate hole, C8

5015 c/z -4.35356 +7.54126 +1.91135 $ Upper grid plate hole, C9

5016 c/z -0.00000 +7.54126 +1.91135 $ Upper grid plate hole, C10

5017 c/z +4.35356 +7.54126 +1.91135 $ Upper grid plate hole, C11

5018 c/z +6.53034 +3.76936 +1.91135 $ Upper grid plate hole, C12

5019 c/z +13.06068 +0.00000 +1.91135 $ Upper grid plate hole, D1

5020 c/z +10.88390 -3.76936 +1.91135 $ Upper grid plate hole, D2

5021 c/z +8.70712 -7.54126 +1.91135 $ Upper grid plate hole, D3

5022 c/z +6.53034 -11.31062 +1.91135 $ Upper grid plate hole, D4

5023 c/z +2.17678 -11.31062 +1.91135 $ Upper grid plate hole, D5

5024 c/z -2.17678 -11.31062 +1.91135 $ Upper grid plate hole, D6

5025 c/z -6.53034 -11.31062 +1.91135 $ Upper grid plate hole, D7

5026 c/z -8.70712 -7.54126 +1.91135 $ Upper grid plate hole, D8

5027 c/z -10.88390 -3.76936 +1.91135 $ Upper grid plate hole, D9

5028 c/z -13.06068 +0.00000 +1.91135 $ Upper grid plate hole, D10

5029 c/z -10.88390 +3.76936 +1.91135 $ Upper grid plate hole, D11

5030 c/z -8.70712 +7.54126 +1.91135 $ Upper grid plate hole, D12

5031 c/z -6.53034 +11.31062 +1.91135 $ Upper grid plate hole, D13

5032 c/z -2.17678 +11.31062 +1.91135 $ Upper grid plate hole, D14

5033 c/z +2.17678 +11.31062 +1.91135 $ Upper grid plate hole, D15

5034 c/z +6.53034 +11.31062 +1.91135 $ Upper grid plate hole, D16

5035 c/z +8.70712 +7.54126 +1.91135 $ Upper grid plate hole, D17

5036 c/z +10.88390 +3.76936 +1.91135 $ Upper grid plate hole, D18

5037 c/z +17.41424 +0.00000 +1.91135 $ Upper grid plate hole, E1

5038 c/z +15.23746 -3.76936 +1.91135 $ Upper grid plate hole, E2

5039 c/z +13.06068 -7.54126 +1.91135 $ Upper grid plate hole, E3

5040 c/z +10.88390 -11.31062 +1.91135 $ Upper grid plate hole, E4

5041 c/z +8.70712 -15.08252 +1.91135 $ Upper grid plate hole, E5

5042 c/z +4.35356 -15.08252 +1.91135 $ Upper grid plate hole, E6

5043 c/z -0.00000 -15.08252 +1.91135 $ Upper grid plate hole, E7

5044 c/z -4.35356 -15.08252 +1.91135 $ Upper grid plate hole, E8

5045 c/z -8.70712 -15.08252 +1.91135 $ Upper grid plate hole, E9

5046 c/z -10.88390 -11.31062 +1.91135 $ Upper grid plate hole, E10

5047 c/z -13.06068 -7.54126 +1.91135 $ Upper grid plate hole, E11

5048 c/z -15.23746 -3.76936 +1.91135 $ Upper grid plate hole, E12

5049 c/z -17.41424 +0.00000 +1.91135 $ Upper grid plate hole, E13

5050 c/z -15.23746 +3.76936 +1.91135 $ Upper grid plate hole, E14

5051 c/z -13.06068 +7.54126 +1.91135 $ Upper grid plate hole, E15

5052 c/z -10.88390 +11.31062 +1.91135 $ Upper grid plate hole, E16

5053 c/z -8.70712 +15.08252 +1.91135 $ Upper grid plate hole, E17

5054 c/z -4.35356 +15.08252 +1.91135 $ Upper grid plate hole, E18

5055 c/z -0.00000 +15.08252 +1.91135 $ Upper grid plate hole, E19

5056 c/z +4.35356 +15.08252 +1.91135 $ Upper grid plate hole, E20

5057 c/z +8.70712 +15.08252 +1.91135 $ Upper grid plate hole, E21

5058 c/z +10.88390 +11.31062 +1.91135 $ Upper grid plate hole, E22

5059 c/z +13.06068 +7.54126 +1.91135 $ Upper grid plate hole, E23

5060 c/z +15.23746 +3.76936 +1.91135 $ Upper grid plate hole, E24

5061 c/z +21.76780 +0.00000 +1.91135 $ Upper grid plate hole, F1

5062 c/z +19.59102 -3.76936 +1.91135 $ Upper grid plate hole, F2

5063 c/z +17.41424 -7.54126 +1.91135 $ Upper grid plate hole, F3

5064 c/z +15.23746 -11.31062 +1.91135 $ Upper grid plate hole, F4

5065 c/z +13.06068 -15.08252 +1.91135 $ Upper grid plate hole, F5

5066 c/z +10.88390 -18.85188 +1.91135 $ Upper grid plate hole, F6

5067 c/z +6.53034 -18.85188 +1.91135 $ Upper grid plate hole, F7

5068 c/z +2.17678 -18.85188 +1.91135 $ Upper grid plate hole, F8

5069 c/z -2.17678 -18.85188 +1.91135 $ Upper grid plate hole, F9

5070 c/z -6.53034 -18.85188 +1.91135 $ Upper grid plate hole, F10

5071 c/z -10.88390 -18.85188 +1.91135 $ Upper grid plate hole, F11

5072 c/z -13.06068 -15.08252 +1.91135 $ Upper grid plate hole, F12

5073 c/z -15.23746 -11.31062 +1.91135 $ Upper grid plate hole, F13

5074 c/z -17.41424 -7.54126 +1.91135 $ Upper grid plate hole, F14

5075 c/z -19.59102 -3.76936 +1.91135 $ Upper grid plate hole, F15

5076 c/z -21.76780 +0.00000 +1.91135 $ Upper grid plate hole, F16

5077 c/z -19.59102 +3.76936 +1.91135 $ Upper grid plate hole, F17

5078 c/z -17.41424 +7.54126 +1.91135 $ Upper grid plate hole, F18

5079 c/z -15.23746 +11.31062 +1.91135 $ Upper grid plate hole, F19

5080 c/z -13.06068 +15.08252 +1.91135 $ Upper grid plate hole, F20

5081 c/z -10.88390 +18.85188 +1.91135 $ Upper grid plate hole, F21

5082 c/z -6.53034 +18.85188 +1.91135 $ Upper grid plate hole, F22

5083 c/z -2.17678 +18.85188 +1.91135 $ Upper grid plate hole, F23

5084 c/z +2.17678 +18.85188 +1.91135 $ Upper grid plate hole, F24

5085 c/z +6.53034 +18.85188 +1.91135 $ Upper grid plate hole, F25

5086 c/z +10.88390 +18.85188 +1.91135 $ Upper grid plate hole, F26

5087 c/z +13.06068 +15.08252 +1.91135 $ Upper grid plate hole, F27

5088 c/z +15.23746 +11.31062 +1.91135 $ Upper grid plate hole, F28

5089 c/z +17.41424 +7.54126 +1.91135 $ Upper grid plate hole, F29

5090 c/z +19.59102 +3.76936 +1.91135 $ Upper grid plate hole, F30

5091 c/z +23.94458 -3.76936 +1.91135 $ Upper grid plate hole, G2

5092 c/z +21.76780 -7.54126 +1.91135 $ Upper grid plate hole, G3

5093 c/z +19.59102 -11.31062 +1.91135 $ Upper grid plate hole, G4

5094 c/z +17.41424 -15.08252 +1.91135 $ Upper grid plate hole, G5

5095 c/z +15.23746 -18.85188 +1.91135 $ Upper grid plate hole, G6

5096 c/z +8.70712 -22.62124 +1.91135 $ Upper grid plate hole, G8

5097 c/z +4.35356 -22.62124 +1.91135 $ Upper grid plate hole, G9

5098 c/z -0.00000 -22.62124 +1.91135 $ Upper grid plate hole, G10

5099 c/z -4.35356 -22.62124 +1.91135 $ Upper grid plate hole, G11

5100 c/z -8.70712 -22.62124 +1.91135 $ Upper grid plate hole, G12

5101 c/z -15.23746 -18.85188 +1.91135 $ Upper grid plate hole, G14

5102 c/z -17.41424 -15.08252 +1.91135 $ Upper grid plate hole, G15

5103 c/z -19.59102 -11.31062 +1.91135 $ Upper grid plate hole, G16

5104 c/z -21.76780 -7.54126 +1.91135 $ Upper grid plate hole, G17

5105 c/z -23.94458 -3.76936 +1.91135 $ Upper grid plate hole, G18

5106 c/z -23.94458 +3.76936 +1.91135 $ Upper grid plate hole, G20

5107 c/z -21.76780 +7.54126 +1.91135 $ Upper grid plate hole, G21

5108 c/z -19.59102 +11.31062 +1.91135 $ Upper grid plate hole, G22

5109 c/z -17.41424 +15.08252 +1.91135 $ Upper grid plate hole, G23

5110 c/z -15.23746 +18.85188 +1.91135 $ Upper grid plate hole, G24

5111 c/z -8.70712 +22.62124 +1.91135 $ Upper grid plate hole, G26

5112 c/z -4.35356 +22.62124 +1.91135 $ Upper grid plate hole, G27

5113 c/z +4.35356 +22.62124 +1.91135 $ Upper grid plate hole, G29

5114 c/z -0.00000 +22.62124 +1.91135 $ Upper grid plate hole, G28

5115 c/z +8.70712 +22.62124 +1.91135 $ Upper grid plate hole, G30

5116 c/z +15.23746 +18.85188 +1.91135 $ Upper grid plate hole, G32

5117 c/z +17.41424 +15.08252 +1.91135 $ Upper grid plate hole, G33

5118 c/z +19.59102 +11.31062 +1.91135 $ Upper grid plate hole, G34

5119 c/z +21.76780 +7.54126 +1.91135 $ Upper grid plate hole, G35

5120 c/z +23.94458 +3.76936 +1.91135 $ Upper grid plate hole, G36

c ---------------------

c Cut planes for tallies

c ---------------------

6000 pz +32

6001 pz +31

6002 pz +30

6003 pz +29

6004 pz +28

6005 pz +27

6006 pz +26

6007 pz +25

6008 pz +24

6009 pz +23

6010 pz +22

6011 pz +21

6012 pz +20

6013 pz +19

6014 pz +18

6015 pz +17

6016 pz +16

6017 pz +15

6018 pz +14

6019 pz +13

6020 pz +12

6021 pz +11

6022 pz +10

6023 pz +9

6024 pz +8

6025 pz +7

6026 pz +6

6027 pz +5

6028 pz +4

6029 pz +3

6030 pz +2

6031 pz +1

6032 pz +0

6033 pz -1

6034 pz -2

6035 pz -3

6036 pz -4

6037 pz -5

6038 pz -6

6039 pz -7

6040 pz -8

6041 pz -9

6042 pz -10

6043 pz -11

6044 pz -12

6045 pz -13

6046 pz -14

6047 pz -15

6048 pz -16

6049 pz -17

6050 pz -18

6051 pz -19

6052 pz -20

6053 pz -21

6054 pz -22

6055 pz -23

6056 pz -24

6057 pz -25

6058 pz -26

6059 pz -27

6060 pz -28

6061 pz -29

6062 pz -30

6063 pz -31

6064 pz -32

6065 pz -33

6066 pz -34

6067 pz -35

6068 pz -36

7000 pz +30.861

7001 pz +27.305

7002 pz +25.781

```
7003 pz +22.225
7004 pz +20.701
7005 pz +17.145
7006 pz +15.621
7007 pz +12.065
7008 pz +10.541
7009 pz +6.985
7010 pz +5.461
7011 pz +1.905
7012 pz +0.381
7013 pz -3.175
7014 pz -4.699
7015 pz -8.255
7016 pz -9.779
7017 pz -13.335
7018 pz -14.859
7019 pz -18.415
7020 pz -19.939
7021 pz -23.495
7022 pz -25.019
7023 pz -28.575
7024 pz -30.099
7025 pz -33.655
7026 pz -35.179
c
8000 pz +30.7975 $ Bottom of upper grid plate region
8001 pz +27.7368 $ Top of graphite region
```

```
 8002 pz +19.05 $ Top of fuel region
 8003 pz -19.05 $ Bottom of fuel region
 8004 pz -27.7368 $ Bottom of graphite region
 8005 pz -33.17875 $ Top of lower grid plate region
c
c --------------------------------
c Tube surface for my test (Alex Zhou 2009)
c ---------------------------------
 9001 rcc +19.59102 +11.31062 0.05 0 0 1.5 0.5 $sample space inside container
 9002 rcc +19.59102 +11.31062 0 0 0 1.6 0.55 $container of polyethylene
 9003 c/z +19.59102 +11.31062 +1.816 $ assembly for G34
 9004 c/z +19.59102 +11.31062 +1.867 $ out shell
c 9010 rcc +19.59102 +11.31062 -1.7 0 0 5 1.5 $ surface source bound
c
c ------------------------------------------------------------
c End of Surface Card Specification
c ------------------------------------------------------------

c ------------------------------------------------------------
c Beginning of Material Card Specification
c ------------------------------------------------------------
c -----------------------
c Beam tube transformations
c -----------------------
c tr1: Through port, small, BP1
c tr2: Tangential port, small, BP2
c tr3: Radial port, large, BP3
```

```
c tr4: Radial port, small, BP4
c tr5: Through port, large, BP5
c
 *tr1 0.0 -35.255 -6.985 00 90 90 90 00 90
 *tr2 +35.255 -06.222 -6.985 30 120 90 60 30 90
 *tr3 0.0 +25.600 -6.985 00 90 90 90 00 90
 *tr4 -22.871 +13.216 -6.985 60 30 90 150 60 90
 *tr5 0.0 -35.255 -6.985 00 90 90 90 00 90
c
c the '*' just makes the transformation in degrees
c
c --------------------------
c Control rod transformations
c --------------------------
c Shutdown condition -000 units
c Low power critical -525 units
c Design high power -700 units
c Full out condition -960 units
c
 tr6 0 0 00.00  1 0 0 0 1 0
 tr7 0 0 23.40  1 0 0 0 1 0 $ Formerly 19.05, 8.33, 12.37
 tr8 0 0 27.78  1 0 0 0 1 0
 tr9 0 0 38.10  1 0 0 0 1 0
c
c ---------------------------------
c Mapping experiment transformations
c ---------------------------------
```

```
 tr10 +2.17678 -1.2573 0.0
 tr11 +15.23746 -1.2573 0.0
 tr12 +19.59102 -1.2573 0.0
 tr13 +23.94458 -1.2573 0.0
c
c -----------------------------------
c Irradiation facility transformations
c -----------------------------------
 tr20 -15.23746 -8.79856 0.0 $ Center of 3L irradiator
 tr50 +15.23746 -11.31062 0.0 $ Center of 6L irradiator
c
c ------------------------------
c Grid plate hole transformations
c ------------------------------
 tr100 -0.00000 +0.00000 0.0 $ A1
 tr101 +4.35356 +0.00000 0.0 $ B1
 tr102 +2.17678 -3.76936 0.0 $ B2
 tr103 -2.17678 -3.76936 0.0 $ B3
 tr104 -4.35356 +0.00000 0.0 $ B4
 tr105 -2.17678 +3.76936 0.0 $ B5
 tr106 +2.17678 +3.76936 0.0 $ B6
 tr107 +8.70712 +0.00000 0.0 $ C1
 tr108 +6.53034 -3.76936 0.0 $ C2
 tr109 +4.35356 -7.54126 0.0 $ C3
 tr110 -0.00000 -7.54126 0.0 $ C4
 tr111 -4.35356 -7.54126 0.0 $ C5
 tr112 -6.53034 -3.76936 0.0 $ C6
```

tr113 -8.70712 +0.00000 0.0 $ C7

tr114 -6.53034 +3.76936 0.0 $ C8

tr115 -4.35356 +7.54126 0.0 $ C9

tr116 -0.00000 +7.54126 0.0 $ C10

tr117 +4.35356 +7.54126 0.0 $ C11

tr118 +6.53034 +3.76936 0.0 $ C12

tr119 +13.06068 +0.00000 0.0 $ D1

tr120 +10.88390 -3.76936 0.0 $ D2

tr121 +8.70712 -7.54126 0.0 $ D3

tr122 +6.53034 -11.31062 0.0 $ D4

tr123 +2.17678 -11.31062 0.0 $ D5

tr124 -2.17678 -11.31062 0.0 $ D6

tr125 -6.53034 -11.31062 0.0 $ D7

tr126 -8.70712 -7.54126 0.0 $ D8

tr127 -10.88390 -3.76936 0.0 $ D9

tr128 -13.06068 +0.00000 0.0 $ D10

tr129 -10.88390 +3.76936 0.0 $ D11

tr130 -8.70712 +7.54126 0.0 $ D12

tr131 -6.53034 +11.31062 0.0 $ D13

tr132 -2.17678 +11.31062 0.0 $ D14

tr133 +2.17678 +11.31062 0.0 $ D15

tr134 +6.53034 +11.31062 0.0 $ D16

tr135 +8.70712 +7.54126 0.0 $ D17

tr136 +10.88390 +3.76936 0.0 $ D18

tr137 +17.41424 +0.00000 0.0 $ E1

tr138 +15.23746 -3.76936 0.0 $ E2

tr139 +13.06068 -7.54126 0.0 $ E3

tr140 +10.88390 -11.31062 0.0 $ E4

tr141 +8.70712 -15.08252 0.0 $ E5

tr142 +4.35356 -15.08252 0.0 $ E6

tr143 -0.00000 -15.08252 0.0 $ E7

tr144 -4.35356 -15.08252 0.0 $ E8

tr145 -8.70712 -15.08252 0.0 $ E9

tr146 -10.88390 -11.31062 0.0 $ E10

tr147 -13.06068 -7.54126 0.0 $ E11

tr148 -15.23746 -3.76936 0.0 $ E12

tr149 -17.41424 +0.00000 0.0 $ E13

tr150 -15.23746 +3.76936 0.0 $ E14

tr151 -13.06068 +7.54126 0.0 $ E15

tr152 -10.88390 +11.31062 0.0 $ E16

tr153 -8.70712 +15.08252 0.0 $ E17

tr154 -4.35356 +15.08252 0.0 $ E18

tr155 -0.00000 +15.08252 0.0 $ E19

tr156 +4.35356 +15.08252 0.0 $ E20

tr157 +8.70712 +15.08252 0.0 $ E21

tr158 +10.88390 +11.31062 0.0 $ E22

tr159 +13.06068 +7.54126 0.0 $ E23

tr160 +15.23746 +3.76936 0.0 $ E24

tr161 +21.76780 +0.00000 0.0 $ F1

tr162 +19.59102 -3.76936 0.0 $ F2

tr163 +17.41424 -7.54126 0.0 $ F3

tr164 +15.23746 -11.31062 0.0 $ F4

tr165 +13.06068 -15.08252 0.0 $ F5

tr166 +10.88390 -18.85188 0.0 $ F6

tr167 +6.53034 -18.85188 0.0 $ F7

tr168 +2.17678 -18.85188 0.0 $ F8

tr169 -2.17678 -18.85188 0.0 $ F9

tr170 -6.53034 -18.85188 0.0 $ F10

tr171 -10.88390 -18.85188 0.0 $ F11

tr172 -13.06068 -15.08252 0.0 $ F12

tr173 -15.23746 -11.31062 0.0 $ F13

tr174 -17.41424 -7.54126 0.0 $ F14

tr175 -19.59102 -3.76936 0.0 $ F15

tr176 -21.76780 +0.00000 0.0 $ F16

tr177 -19.59102 +3.76936 0.0 $ F17

tr178 -17.41424 +7.54126 0.0 $ F18

tr179 -15.23746 +11.31062 0.0 $ F19

tr180 -13.06068 +15.08252 0.0 $ F20

tr181 -10.88390 +18.85188 0.0 $ F21

tr182 -6.53034 +18.85188 0.0 $ F22

tr183 -2.17678 +18.85188 0.0 $ F23

tr184 +2.17678 +18.85188 0.0 $ F24

tr185 +6.53034 +18.85188 0.0 $ F25

tr186 +10.88390 +18.85188 0.0 $ F26

tr187 +13.06068 +15.08252 0.0 $ F27

tr188 +15.23746 +11.31062 0.0 $ F28

tr189 +17.41424 +7.54126 0.0 $ F29

tr190 +19.59102 +3.76936 0.0 $ F30

tr191 +23.94458 -3.76936 0.0 $ G2

tr192 +21.76780 -7.54126 0.0 $ G3

tr193 +19.59102 -11.31062 0.0 $ G4

tr194 +17.41424 -15.08252 0.0 $ G5

tr195 +15.23746 -18.85188 0.0 $ G6

tr196 +8.70712 -22.62124 0.0 $ G8

tr197 +4.35356 -22.62124 0.0 $ G9

tr198 -0.00000 -22.62124 0.0 $ G10

tr199 -4.35356 -22.62124 0.0 $ G11

tr200 -8.70712 -22.62124 0.0 $ G12

tr201 -15.23746 -18.85188 0.0 $ G14

tr202 -17.41424 -15.08252 0.0 $ G15

tr203 -19.59102 -11.31062 0.0 $ G16

tr204 -21.76780 -7.54126 0.0 $ G17

tr205 -23.94458 -3.76936 0.0 $ G18

tr206 -23.94458 +3.76936 0.0 $ G20

tr207 -21.76780 +7.54126 0.0 $ G21

tr208 -19.59102 +11.31062 0.0 $ G22

tr209 -17.41424 +15.08252 0.0 $ G23

tr210 -15.23746 +18.85188 0.0 $ G24

tr211 -8.70712 +22.62124 0.0 $ G26

tr212 -4.35356 +22.62124 0.0 $ G27

tr213 +4.35356 +22.62124 0.0 $ G29

tr214 -0.00000 +22.62124 0.0 $ G28

tr215 +8.70712 +22.62124 0.0 $ G30

tr216 +15.23746 +18.85188 0.0 $ G32

tr217 +17.41424 +15.08252 0.0 $ G33

c tr218 +19.59102 +11.31062 0.0 $ G34

tr219 +21.76780 +7.54126 0.0 $ G35

tr220 +23.94458 +3.76936 0.0 $ G36

```
c
c --------------------------
c Reactor component materials
c --------------------------
c m1 -water
c m2 -aluminum (structural) type 6061
c m3 -stainless steel (structural) type 304
c m4 -graphite (carbon)
c m5 -fresh U-ZrH fuel
c m6 -B4C (boron carbide)
c m7 -zirconium (rod)
c m8 -air
c m10 -cadmium (neutron absorber liner)
c m11 -lead (neutron absorber liner)
c
 m1  1001 0.66667
     8016 0.33333
 mt1 lwtr.60t
c mpn1 0 0
 m2  13027 -0.9685
     26000.50c -0.0070
     29000.50c -0.0025
     14000.60c -0.0060
     12000.66c -0.0110
     24000.50c -0.0035
     25055 -0.0015
c
```

```
c mpn2 0 0 0 0 0 0 0
 m3  26000.50c -0.6785
     6000 -0.0080
     14000.60c -0.0100
     24000.50c -0.1800
     28000.50c -0.0980
     25055 -0.0180
     15031 -0.0045
     16000.66c -0.0030
c
c mpn3 0 0 0 0 0 0 0 0
c
 m4  6000 1.0
 mt4 grph.60t $ 300K
c mpn4 0
c
 m5  40090 -0.462589265
     40091 -0.100879525
     40092 -0.154196422
     40094 -0.156264362
     40096 -0.025174926
     1001 -0.0158955
     92238 -0.068170
     92235 -0.016830
c
c mpn5 0 0 82208 82208
  mt5 zr/h.60t
```

```
     h/zr.60t
c
 m6  5010 0.1584
     5011 0.6416
     6000 0.2
c
c mpn6 0 0 0
 m7  40090 51.45
     40091 11.22
     40092 17.15
     40094 17.38
     40096 2.8
c
c mpn7 0
 m8  8016 -0.23
     7014 -0.77
c mpn8 0 0
 m10 48000.42c 1.0
c mpn10 0
 m11 82000.42c -1.0
c
c mpn11 0
 m12 28058 1 $ nickel (n,p) a/o 68.0
 m13 28064 1 $ nickel (n,g) a/o 0.9
 m14 79197 1 $ gold (n,g) a/o 100.0
 m15 29063 1 $ copper (n,g) a/o 69.1
 m16 26058 1 $ iron (n,g) a/o 0.2
```

```
 m17 26054 1 $ iron (n,p) a/o 5.8
 m18 42098 1 $ molybdenum (n,g) a/o 24.1
 m19 27059 1 $ cobalt (n,g) a/o 100.0
 m20 13027 1 $ aluminum (n,g) a/o 100.0
 m21 14000.60c -0.005 $ 1100 borated aluminum alloy
     26000.50c -0.005
     29000.50c -0.001
     25055 -0.005
     30000.42c -0.0001
     5010 -0.04275
     5011 -0.00225
     13027 -0.9389
c
 m22 26056 1 $ Iron (n,p) a/o 91.754
 m23 57139 1 $ Lanthanum (n,g) a/o 99.9098
 m24 73181 1 $ Tantalum (n,g) a/o 99.988
 m25 22047 1 $ Titanium (n,p) a/o 7.44
 m26 22048 1 $ Titanium (n,p) a/o 73.72
 m27 14030 1 $ Silicon (n,x) a/o 3.1
 m28 24050 1 $ Chromium (n,x) a/o 4.345
 m29 29065 1 $ Copper (n,x) a/o 30.83
 m30 50112 1 $ Tin (n,x) a/o 0.97
 m31 50116 1 $ Tin (n,x) a/o 14.54
 m32 50118 1 $ Tin (n,x) a/o 24.22
 m33 50122 1 $ Tin (n,x) a/o 4.63
 m34 50124 1 $ Tin (n,x) a/o 5.79
 m35 82204 1 $ Lead (n,x) a/o 1.4
```

```
 m36 82206 1 $ Lead (n,x) a/o 24.1
 m37 18040 1 $ Argon (n,g) a/o 99.6003
 m38 24052 1 $ Chromium (n,p) a/o 83.789
 m39 22050 1 $ Titanium (n,g) a/o 5.18
 m40 42100 1 $ Molybdenum (n,g) a/o 9.63
 m41 16032 1 $ Sulfur-32 (n,p) a/o 95.02
c
c ---------------------------------
c Tube material for my test (Alex Zhou 2009)
c ----------------------------------
 m99  1001 2
      6012 1
 MT99 POLY.60t $ CH2, polyethylene
 m9910 1001 -.11111  $ .001% NaCl solution
       8016 -.88888
       11023 -3.93E-6
       17000 -6.07E-6
 m9911 1001 -.1111  $ .01% NaCl solution
       8016 -.8888
       11023 -3.93E-5
       17000 -6.07E-5
 m9912 1001 -.111  $ .1% NaCl solution
       8016 -.888
       11023 -3.93E-4
       17000 -6.07E-4
 m9913 1001 -.11  $ 1% NaCl solution
       8016 -.88
```

```
      11023 -3.93E-3
      17000 -6.07E-3
 m9914 1001 -.1  $ 10% NaCl solution
      8016 -.8
      11023 -3.93E-2
      17000 -6.07E-2
 m9992 2001 .667
      8016 .333
 MT9992 hwtr.60c
 m9993 11023 1 $ Na
 m9994 17000 1 $ Cl
 m9995 1001 1 $ H
 m9996 1002 1 $ D
c
c ----------------------
c Criticality calculation
c ----------------------
c 10000 n/cycle, 1.000 as initial guess, skip 30, total of 60 keff cycles,
c automatic plotting of three combined keff tally
c
 kcode 10000 1.000 30 60 4500 0 6500 1
 mplot freq 10 kcode 16 scales 2
 ksrc -4.5 21.8 13 0 21.8 13 4.5 21.8 13 -11 18 13
     -6.5 18.0 13 -2 18.0 13 2.0 18 13 6.5 18 13
     11 18 13 -17.5 14.3 13 -13 14.3 13 -9 14.3 13
     -4.5 14.3 13 0 14.3 13 4.5 14.3 13 9 14.3 13
     13 14.3 13 -19.5 10.5 13 -15.5 10.5 13 -11 10.5 13
```

```
     -6.5 10.5 13 2 10.5 13 6.5 10.5 13 11 10.5 13
     15.5 10.5 13 19.5 10.5 13 -22 6.8 13 -17.5 6.8 13
     -13 6.8 13 -9 6.8 13 -4.5 6.8 13 0 6.8 13
     4.5 6.8 13 9 6.8 13 13 6.8 13 17.5 6.8 13
     -19.5 2.8 13 -15.5 2.8 13 -11 2.8 13 -6.5 2.8 13
     -2 2.8 13 2 2.8 13 6.5 2.8 13 11 2.8 13
     15.5 2.8 13 19.5 2.8 13 -22 -0.8 13 -17.5 -0.8 13
     -13 -0.8 13 -4.5 -0.8 13 4.5 -0.8 13 13 -0.8 13
     17.5 -0.8 13 22 -0.8 13 -24 -4.6 13 -19.5 -4.6 13
     -15.5 -4.6 13 -11 -4.6 13 -6.5 -4.6 13 -2 -4.6 13
     2 -4.6 13 6.5 -4.6 13 11 -4.6 13 15.5 -4.6 13
     19.5 -4.6 13 -22 -8.3 13 -9 -8.3 13 -4.5 -8.3 13
     0 -8.3 13 4.5 -8.3 13 9 -8.3 13 13 -8.3 13
     17.5 -8.3 13 22 -8.3 13 -11 -12 13 -6.5 -12 13
     2 -12 13 6.5 -12 13 11 -12 13 15.5 -12 13
     19.5 -12 13 -17.5 -15.9 13 -13 -15.9 13 -9 -15.9 13
     -4.5 -15.9 13 0 -15.9 13 4.5 -15.9 13 9 -15.9 13
     13 -15.9 13 17.5 -15.9 13 -15.5 -19.7 13 -11 -19.7 13
     -6.5 -19.7 13 -2 -19.7 13 2 -19.7 13 6.5 -19.7 13
     11 -19.7 13 -4.5 -23.5 13 0 -23.5 13 4.5 -23.5 13
c
 thtme 0 $ time in shakes (1e-8 sec) at which thermal temperatures...
 mode n p
c phys:p 100 0 0 0 1 -102 $ -102, Analog sampling, models only, multigroup + line emission
 imp:n 1 314r 0
 imp:p 1 314r 0
c F4:n 124
```

```
c energy band: thermal, epithermal, and fast
c ssW -9010 -111 121
 E4 1E-6 1E-3 1
 F7:n 124
 F4:n 9001
 FM4 (4.97e+7 9993 -1) (4.97e+7 9994 -1) (2.91e13 9995 -1)
 FC4
print
```